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The above mentioned authors and a number of others including *Maatz, Lentz & Graf* (1954) *Enneking* (1962) *Bonfiglio* (1958) *Nil sonne* (1963) and *Burwell* (1964) consider that the chance of incorpo ration is best for autoplants followed by homoplants and then hetero plants In a dissertation published in 1954 and a revision of it in 1959 Bauermeister (at the Kiel Surgical Department) has reported the ex periments that led to the introduction of Kiel Bone He used a spon giosa test published by *Maatz et al* (1954) in which small plugs of cancellous bone to be tested or compared are transplanted side by side in the spongiosa of the dog Evidence of incorporation will usually be present after 2 weeks In over 300 experiments Bauermeister used this technique for comparing auto homo and heterologous transplants *and those of bone treated in some 20 different ways The experiments* included heterotopic transplantation in the back muscle of the dog and tests of mechanical strength On the properties of the tested material Bauermeister reached the following conclusions the rate of healing is greatly dependent on the surface area per unit volume bone fine meshed cancellous bone is in this respect better than coarse cancel lous or compact bone the age of the donor is important bone from newborn takes one third to one half the time required for that from adults Too thorough removal of proteins in the bone by for instance heating in an open flame or boiling with solvents greatly reduces the strength of the material

On the basis of this experience Kiel Bone is prepared in the following manner Bone from calves or pigs a few weeks old is cleaned coarsely and sawn into standardized pieces of compact or cancellous *bone* suitable for surgical use These are treated for 48 hours with 20 per cent hydrogen peroxide at 37 After washing in water for one day and drying the fat is removed and the pieces are sterilized in ether or acetone vapour for 15–24 hours

Bauermeister claims that this material approaches and is in some respects even superior to autologous bone as regards the osteogenic activity in cancellous plugs and that in any case it is superior to homoplants It compares with fresh bone in strength and has no anti genic properties Summarizing his assessment of the various types as

transplant materials he accords fresh autologous bone first place followed in turn by Kiel Bone banked homologous fresh homologous and fresh heterologous bone

The treatment with hydrogen peroxide would seem to reduce the antigenic properties of the proteins by oxidizing the side chains in the *amino acids This results in a change in the secondary and the in this* context important tertiary structure (*Paul* 1964)

In chemical analysis of cancellous Kiel Bone we have found a fat content of 3 5 per cent on extraction by Soxhlet s method (2 hours in petroleum ether and 2 hours in ethanol) Though Bauermeister does not specify the protein content of Kiel Bone it is obvious that he con *siders it to be extremely low*

On subjecting Kiel Bone to x ray crystallographic examinations after decalcification *Gallow & Muh enberg* (1963) found close similarities to pure collagen and they consider that the material is not deprived of protein to any large extent *Fuchs et al* (1963) reached the same conclusion by chemical analysis However they also verified Bauer *meister s results regarding the callus forming properties of Kiel Bone* which they found quite comparable with those of autoplants

From the several reports of clinical results published in recent years it is evident that Kiel Bone is in general use at many of the larger sur gical and orthopaedic departments in Germany From 7 of these 705 cases have been compiled (Kiel [*Bauermeister* 1961 *Lubinus* 1963] Berlin [*Vaal* 1963 *Koch & Dahmen* 1962] and Heidelberg [*Hopf*]) Most of the indications for bone transplantation are represented here

The material has been variously assessed Hopf recorded failures in no less than 44 per cent of 142 cases 20 per cent of them through infection As a rule however the figures are considerably more favour able with a mean proportion of failures of 18 per cent Among the good results are those reported by Popkirov who obtained primary healing in 20 and secondary healing in 4 cases of chronic osteomyelitis (22 cases) and tuberculous osteitis (2 cases) Lubinus obtained good results in all 19 cases of intercorporal fusion operations in the lumbar spine

In a recent paper on the indications and contra indications of the use of Kiel Bone *Williams* (1964) reports the application of this ma terial for compact grafts in 7 cases of non union of the tibia and 1 of the femur He infers from his results that Kiel Bone is a very useful substance in the armamentarium of the orthopaedic and traumatic surgeon

by cells of the host tissue and the transplant can fulfil certain simple mechanical functions. It is thus no disadvantage if the homo- and heteroplants are dead when they are inserted; on the contrary, some degree of denaturation—for instance by freeze drying—has even been considered to be to the good.

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On the basis of this experience Kiel Bone is prepared in the following manner. Bone from calves or pigs a few weeks old is cleaned coarsely and sawn into standardized pieces of compact or cancellous bone suitable for surgical use. These are treated for 48 hours with 20 per cent hydrogen peroxide at 37°. After washing in water for one day and drying, the fat is removed and the pieces are sterilized in ether or acetone vapour for 15–24 hours.

Bauermeister claims that this material approaches and is in some respects even superior to autologous bone as regards the osteogenic activity in cancellous plugs, and that in any case it is superior to homoplants. It compares with fresh bone in strength and has no antigenic properties. Summarizing his assessment of the various types as


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All 12 plugs in the specimens removed after *two weeks* were found and identified In one slide the Kiel plug was in contact with the compact bone where periosteal bone formation complicated the evaluation All the transplants had healed and there was intense callus formation which had also reached the centre of the plugs All the trabeculae of the transplants were devoid of stainable cell nuclei but were surrounded by zones of vital new bone—creeping substitution—*with active osteoblast zones and distinct osteocytes osteoclasts were* numerous In the Kiel plugs the dead trabeculae were more or less dissolved (an effect of decalcification) and were sometimes entirely absent Osteogenesis was however as good as in the auto and homo plants nor was there any fundamental difference between the three types as regards healing or inflammatory granulation tissue There were no signs of sloughing or encapsulation

In 2 of the 4 specimens removed after *18 days* the various plugs could not be identified with confidence but in the other 2 all the plugs were easily recognized (Figure 1) Here too bone formation had reached the centre of the plugs with creeping substitution of the dead trabeculae of the transplants In the Kiel plugs these had been partly dissolved during the decalcification just as in the two week specimens In one dog osteogenesis was slightly more intense in the autologous plug than in the other 2 and in another animal the same applied to the Kiel graft By and large however there was little to choose between the 3 materials as regards the properties under consideration and none of the transplants displayed any evidence of sloughing

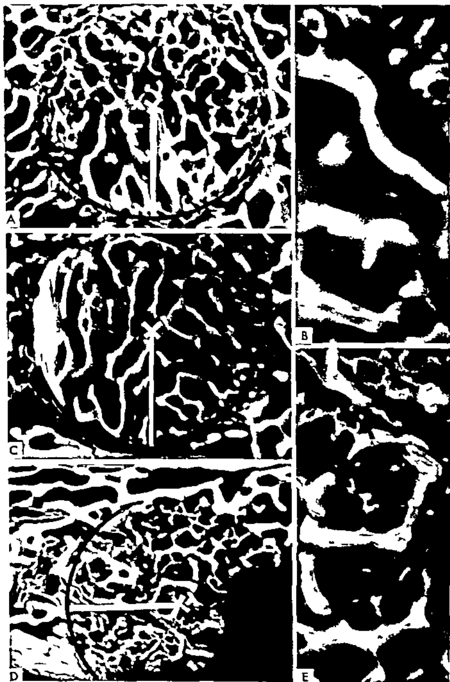
One of the *three week specimens* could not be evaluated with certainty In one of the others all 3 plugs exhibited sparser bone formation towards the centre The zones of new bone around the trabeculae of the transplant were possibly slightly narrower in one of the homo

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*Figure 2 Spongiosa test on dog after 18 days Microradiogram exposed at 20 KV and 20 mA for 10 minutes on Kodak M R film in a Philips X ray diffraction apparatus Model PW 1009 with copper anode and nickel filter All sections 80 microns*

*A C D*—Survey pictures *ca* × 10 Cross sections of test plugs (*cf* Figure 1)

*B E*—Details *ca* × 45 *A B* Autoplants *C* Homoplants *D F* Kiel Bone In *A C* and *D* there is a peripheral zone of new slender poorly mineralized trabeculae (*grey*) connecting the host cancellous bone and the transplant In *B* and *E* there is poorly mineralized bone (*grey*) seen as zones surrounding the more strongly mineralized trabeculae of the transplants (*white*)


A
B
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logous plugs than in the others Otherwise the pictures in the various test bodies were basically the same

After *four weeks* there was no consistent difference between the three types All the grafts were easily evaluated The fact that this host dog was among the oldest—4 years—may explain the low osteo genetic activity in several of the plugs In this dog too the bone formation in one of the slides was not very pronounced in the centre of the plugs and in several of them the rims of vital bone were narrow

In the *six week specimens* the healing of the grafts was slightly more complete and there was difficulty in 2 cases *in distinguishing the con* tours of the auto and homoplants The dead trabeculae were narrow but they were present in all the grafts The osteogenesis was possibly less intense than earlier the inflammatory reaction in the marrow was less marked and the marrow rich in fat There was no difference in these respects between the three types of transplants

After fixing in alcohol and embedding in methacrylate ground sec tions[1] were prepared from some representative transplants from 2 of the dogs (Figure 2) The conventional microscopic findings were con firmed in principle As a rule the individual transplants were more easily recognized in the microradiograms than in the routine sections *In all the transplants the gap between the host cancellous bone of the* recipient and the trabeculae of the transplant was bridged by a zone of slender poorly mineralized trabeculae (Figures 2 A C D) and similar structures often lined the coarse trabeculae of the transplant

*Table 1 Survey of the behaviour of the test material*
(Spongiosa test on the dog)

| Criteria | Period of test | | | |
|---|---|---|---|---|
| | 2 wk | 18 d 3 wk | 4 wk | 6 wk |
| Callus formation | + + | + + | + + | + + |
| Formation of new bone towards the centre | + + | + + | + + | + + |
| Creeping subsitution | + + | + | + + | + + |
| Sloughing reaction | — | — | — | — |
| Encapsulation | — | — | — | — |

[1] We would like to extend our thanks to Professor T Arwill Department of Oral Histology for placing his department s resources at our disposal

From the cancellous bone experiments on the dog it is thus evident that new bone was being formed in the centre of the transplant after only 2 weeks (Table 1) However even after 6 weeks the whole of the transplant had apparently not been replaced The essential difference between the two- and six week specimens is thus the reduction in inflammatory reaction and the extension of fatty bone marrow between the new cancellous trabeculae in the transplant As expected the new bone was not so well mineralized as the cancellous trabeculae of either the host of the transplant

The Kiel Bone almost invariably displayed a peculiar picture for the bone which had been macerated prior to buring dissolved during histological preparation with the disappearance of many of the trabeculae This feature differed slightly in the various microscope preparations In these specimens the new rims of vital cellular bone with their osteoblast zones surrounded empty spaces which in the auto and homoplants correspond to the non vital trabeculae of the transplant This feature has also been described by Bauermeister and Fuchs & Stegemann The interpretation is confirmed by the microradiographic study in which the non vital trabeculae of the Kiel grafts are more strongly mineralized than those of the new bone Otherwise the Kiel Bone in these experiments did not differ from the auto and homoplants In no case was there evidence of an appreciable foreign body reaction nor were there signs of sloughing or encapsulation Thus in all 3 types there was clear evidence of osteogenesis after only 2 weeks with wide osteoblast zones but there was also marked osteoclasia even in the centre of the plugs with vascularization and creeping substitution along the trabeculae of the transplanted cancellous bone The amount of new bone seemed to vary slightly from graft to graft and the cellular activity in several of them seemed to be quite as intense in the Kiel Bone as in auto- and homoplants

As no quantitative determination of the new bone was made the only conclusion that could be drawn from the experiments on the dog is that there was no consistent difference between the 3 materials as regards healing in the cancellous bone

## SPONGIOSA TEST ON MAN

To examine whether the findings in the dog are applicable to man the spongiosa test was performed in connection with 4 operations on the hip—3 of them on women and one on a man 50 tto 70 years of age

The operations were performed under spinal anaesthesia Before the surgical wound was closed a small area of the greater trochanter was exposed and 3 plugs were inserted by the same method as that used for the dogs The fresh autoplants the homoplants and the Kiel Bone were placed in that order in the cranial—caudal direction The homoplants for all 4 subjects were obtained from the same specimen of stored cancellous bone preserved at —20 for 4 months The position of the plugs was marked with 2 small stainless steel pins With these as a guide the area was exposed again after 3–4 weeks and the piece of trochanter containing the plugs—about 1 by 1 by 3 cm—was chiselled out The cranical end was labelled with a steel wire suture The preparation and the microscopic techniques were the same as for the experiments on the dog except that no microradiography was performed In none of the 4 subjects were postoperative complications encountered

The cancellous bone of the greater trochanter of these patients differed considerably from that of the dogs It was loose in structure porous and brittle and it was difficult to drill clean channels for the plugs In 2 cases the cylinders of cancellous bone fractured during removal and 2 of the plugs loosened All of the grafts could be identified and evaluated under the microscope except for one only vestiges of which could be found

The Kiel Bone was finer in structure and denser than the auto and homoplants In all cases the healing after 3–4 weeks was less advanced than it had been in the dog after only 2 weeks In some cases osteogenesis had not extended to the centre of the plugs the zones of vital new bone around the non vital trabeculae being narrow and the cellular activity less intense All the transplants displayed evidence of osteoclasis with high osteoblastic activity around their trabeculae and no signs of fibrous encapsulation or sloughing (Figure 3)

The spongiosa test with Kiel Bone homologous banked bone and fresh autologous bone in the 4 patients yielded similar results to those

*Figure 3* *Spongiosa test on man after 3 weeks Haematoxylin eosin stain*
*A C E*—Survey picture *ca* × 10 Cross sections of test plugs *B D F*—Detail *ca* × 100 *A B* Autoplants *C D* Homoplants *E F* Kiel Bone
From comparison of the survey pictures the *finer structure of the Kiel Bone is evident* *B D* and *F* contain narrow zones with new bone around the non vital trabeculae of the transplants (For notation see Figure 1)


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B
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F

recorded in the dog Healing appeared to be slightly slower but there was no consistent difference between the 3 types of transplants as regards the criteria of healing considered

## CLINICAL EXPERIENCE

Between August 1962 and October 1963 Kiel Bone was used for transplants in 53 patients for which the follow up period is at present between one and 2½ years The cases are divided into 3 groups with respect to the mechanical stress to which the grafts were exposed (Table 2)

*Table 2 Clinical results obtained with Kiel Bone*

| Requirements on the material | Number of operations | Results | | | |
|---|---|---|---|---|---|
| | | Good | Uncertain | Poor | Infection |
| Obliteration of cavities | 18 | 16 | 2 | 0 | 2 |
| Low stress | 11 | 8 | 1 | 2 | 0 |
| High stress | 24 | 9 | 4 | 11 | 5 |
| Total | 53 | 33 | 7 | 13 | 7 |

In a number of the cases the results were recorded as Uncertain for instance when the transplant had healed in spite of infection when the follow up period had been too short or as in one case when the patient could not be followed up

The group Cavity obliteration contains 5 cases of cysts or tumours 2 of osteomyelitis 2 of necrosis of the femoral head and 9 other defects or cavities in connection with orthopaedic operations Cancellous bone was generally used The mechanical demands on the transplants in this group were small or nil and a satisfactory result was recorded if there was incorporation with no sign of an immunity reaction

The Low stress group consisted of 5 wedge osteotomies 3 of them in the calcaneus by Dwyer s method 2 fractures of the calcaneus one hip arthrodesis by Britton s method and 3 subtalar arthrodeses by Grice s technique Cancellous bone was generally used and it was usually exposed to compressive stress In one case a wedge placed in a tibia osteotomy collapsed and in another—a hip arthrodesis—there was no evidence of incorporation

The High stress group comprised 16 pseudarthroses 4 arthrodeses and 4 posterior fusion operations in the lumbar spine Cortical grafts

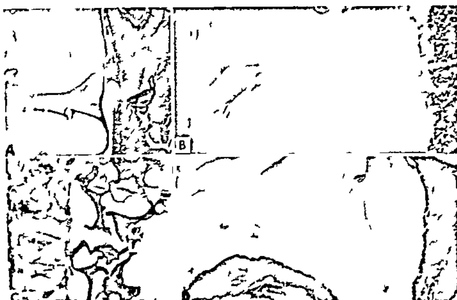



*Figure 4 Cortical Kiel Bone graft used in pseudo arthrosis operation removed after 8 months Haematoxylin eosin stain A C × 10 B D × 40*

**The cortical bone is dead and surrounded like the cancellous trabeculae by protein rich inflammatory granulation tissue In neither the cancellous nor the cortical bone is there evidence of osteogenesis**

were usually employed Eleven of the 13 failures were in this group as were 5 of the 7 cases of infection some of them among the failures

In 3 of the failures cancellous bone had been chosen in situations in which the mechanical stress proved to be so great that cortical bone would have been preferable The importance of obtaining extensive contact with the surrounding vital bone has often been pointed out In 2 of the cases both tumour resections (one of them with intense irradiation) this requirement was not given due consideration and poor union resulted

Among the failures in this group there were also 3 lumbar fusion operations and 3 cases in which cortical bone had been placed in grooves to serve as a bridge and to secure immobilization in the case of non union (inlay technique) In 3 cases the grafts had been removed after 8–13 months and showed that the compact surface behaved like an inert sequestrum although some albeit inadequate union had taken place between the cancellous surface and the surrounding bone In one case the graft had fractured Microscopic exami

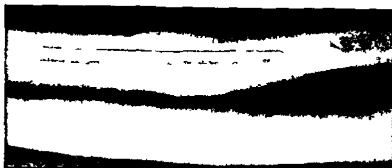


*Figure 5 Cortical Kiel Bone used as an inlay transplant 8 months after a pseud arthrosis operation on the radius The pseudo arthrosis has healed but the graft is still clearly outlined*



*Figure 6 Wedge osteotomy by Dwyer s method performed simultaneously in both heels for congenital club foot Eight months after the operation the results was clinically satisfactory and no difference could be seen between the two sides*

*A* Cancellous Kiel Bone transplant still clearly outlined
*B* Autoplant incorporation almost complete

nation of the 5 specimens removed all of which are thus numbered among the clinical failures disclosed no evidence of osteogenesis in either the compact or cancellous parts In the Haversian canals and between the trabeculae of the cancellous bone organized granulation tissue was found which contained osteoclasts but not with osteoblast zones as in the spongiosa test and there were no zones of new vital bone (Figure 4)

The inlay technique used in some cases was applied in 10 cases of non unions and in 7 of them there was solid union of the fractures

Published radiographs of Kiel transplants often give the impressio that healing took place with unusual rapidity This seemed not to b so striking in the present study Sometimes after more than one yea grafts of compact bone which are highly radiopaque were surrounde by a distinct narrow fairly radiolucent zone (Figure 5) even dece cancellous bone retained its sharp outline for a long period In on case of club foot in which a wedge osteotomy had been performe by Dwyer's method on both heels at an interval of a few days auto logous bone was used on one side and Kiel Bone on the other After months the latter was still more clearly distinguishable than the auto plant Clinical examination however did not disclose any differenc between the two sides (Figure 6)

## DISCUSSION

In Maatz spongiosa test which was used in the present study th healing conditions were standardized for the material under exami nation By placing the transplant in cancellous bone the perioste osteogenesis which is often difficult to assess is avoided ideal grow conditions are obtained and it is possible to get an impression of th value of the transplant material in a matter of 2 weeks or so Since ou tests of Kiel Bone like those by Bauermeister were performed o cancellous bone the results are not directly applicable for clinical us where cortical bone is often transplanted into a bed of like bone an where the conditions for healing are therefore considerably less favou able than in the spongiosa test

The present results bear out Bauermeister's view that in the spon giosa test on the dog cancellous Kiel Bone promotes callus formatio that 2 weeks are enough to obtain healing with osteogenesis right t the centre of the bone plugs and that the material apparently do not elicit a foreign body reaction In these respects there was no ev dent difference between Kiel Bone fresh autoplants and homologou banked bone Since at the end of the 6 week observation period th test materials displayed no difference in resorption of the non vit bone trabeculae it is impossible to judge whether the Kiel Bone wa incorporated more slowly than the other materials some of the radi graphs would suggest that this was the case the material appearin to retain its characteristic structure over a long period

In contrast to Bauermeister's findings but in agreement with thos of other authors (8 9) Kiel Bone was found to contain a considerabl

## ZUSAMMENFASSUNG

Kiel Knochen ist ein Material das aus entfettetem in Wasserstoff Hyperoxid mazerierten Kalbsknochen zubereitet wird Um einen Eindruck über den Wert dieses Materiales als Transplantat zu erhalten wurden Versuche an Hunden vorgenommen und vergleichende Untersuchungen mit einer ähnlichen Technik wurden am Menschen gemacht Erfahrungen mit Kiel Knochen wurden auch mittels klinischer orthopädischer Arbeit bei 53 Patienten über einem Zeitraum von 2 Jahren erhalten

In den Versuchen an Hunden wurde Kiel Markknochen mit frischem autologien oder aufbewahrten homologen Knochen mittels der Spongiosaprobe verglichen Hinsichtlich der 5 Heilungskennzeichen die besonders studiert wurden und aus Mikroröntgenogrammen war es ersichtlich dass Kiel Knochen sich nicht wesentlich von Auto oder Homotransplantaten unterschied

Die Ergebnisse beim Menschen waren gleichartig

Man soll jedoch in Betracht ziehen dass die Spongiosaprobe optimale Heilungsbedingungen schafft und dass die Ergebnisse daher nicht ohne weiteres in der Praxis anwendbar sind In der klinischen Arbeit jedoch waren die mit Kiel Spongiosaknochen erzielten Resultate im allgemeinen zufriedenstellend und er scheint zur Ausschaltung von Hohlräumen verwendbar zu sein Er verträgt auch mässige Druckbeanspruchung Transplantate aus Kortikalisknochen wurden ebenfalls mit Erfolg verwendet wo ein guter Kontakt mit lebensfähigem Wirtsknochen erhalten werden konnte und wo die mechanische Beanspruchung nicht übermässig war Das Material erwies sich jedoch andrerseits als ungeeignet zur Überbrückung von Knochendefekten

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# HEALING OF AMPUTATION STUMPS, WITH SPECIAL REFERENCE TO VASCULARITY AND BONE

By

UNO ERIKSON AND SVEN OLERUD

Received 13 V 65

## INTRODUCTION

*Hulth & Olerud* (1962) have previously shown by angiography hyper vascularization with tortuous arteries in amputation stumps in rabbits They studied the animal by means of manual contrast injection performing the exposure during contrast passage The investigation could not be repeated at different intervals on any one animal and the veins did not always fill particularly well

*Leriche* (1950) *Erikson & Hulth* (1962) and *Erikson* (1965) report similar findings in man on the investigation of small groups of leg amputees It was not possible with the method used however to study the course of vascular development especially in the period immediately following the amputation Not until after 3–4 weeks were the first arteriographies obtained in these amputees

We have considered it of interest to study the process of recovery in the stump both immediately after and a short period after amputation and have attempted to do this by experiments on rabbits

## MATERIAL AND METHODS

a) *Operative Procedure*

15 albino rabbits weighing 2 5–3 kg were amputated unilaterally below the knee under nembutal anaesthesia The usual sterility was observed and special attention was paid to careful haemostasis The tibia was sawn with a circular saw at the level between first and second third Available muscle was sutured over the bone stump and the tendons and skin were then sutured with catgut The animals were placed in cages the floor of which was covered with sawdust in order to prevent decubital sores in the amputation area

b) *Angiographic Procedure*

Angiographies were performed according to an experimental method described by *Ekholm Erikson & Sloglund* (1964) 25 per cent Th O₂ solution (thorotrast) in a dose of 10 ml/kg body weight was injected intravenously whereby the greater part of both the arterial and the venous network remained visible for 1½ hours In two rabbits the vascular system was filled before the amputation The other rabbits divided into seven groups of two The respective groups were studied after 1 day 2 days 3 days 7 days 21 days and 6 weeks and one animal after 4 months In 3 rabbits the investigation was repeated on up to 3 different occasions 7 rabbits were investigated twice and 10 rabbits once

Single exposure was used The focus film distance was 125 cms and the animal lay on the film cassette Exposure data 65 kV 0 010 S 250 mA The film was developed in an automatic developing machine

## RESULTS

### Angiographic Results

The angiographies were evaluated with respect to the width of the large arteries and veins The tortuosity and richness of the peripheral vessels in the amputation stump were noted and as far as possible graded

The arrangement of the vascular pattern indicated in some cases the presence of a haematoma in the stump

### Vascular Width

The arteries and veins were found to be narrower on angiography immediately after the amputation and during the first 24 hours than on pre operative angiography in all 9 rabbits were investigated at



*Figure 1 Amputation stump investigated immediately after amputation The contrast medium thorotrast was injected 90 minutes before the amputation Note the relatively narrow vessels and the haematoma at the distal end of the stump*



*Figure 2 The same stump as in Figure 1 investigated 1 day after amputation The spur shaped haematoma is visible because of thorotrast injected before amputation A second dose of thorotrast made the rather narrow vessels visible*

these times (Figures 1 and 2) Two of the rabbits were investigated twice Three days post operatively a widening of the arteries and veins in the amputated leg was observed in all 4 rabbits investigated at this time (Figure 3) This widening increased progressively and was in some cases even more pronounced after 4 weeks remaining unchanged after 4 montths in all 3 rabbits observed during this period

### *Vascular Richness*

Angiographies of animals investigated immediately after the amputation showed no increase in vascular richness In all animals investigated 3 days or longer after the amputation increased vascular richness was seen (Figures 4 and 5) This development which thus took place parallel with the vascular width changes was found to be more pronounced 3–4 weeks after amputattion (see Figures 6 and 7)

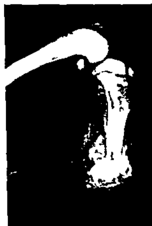


*Figure 3 A stump investigated 3 days after amputation The haematoma is visible due to the injection of thorotrast 6 hours after amputation The vessels at the distal end of the stump surround the haematoma*



*Figure 4 A stump 7 days after amputation The vessels are dilated and the vascularization is increased Owing to thorotrast given for an investigation 4 days earlier dense contrast filled regions are visible No haematoma was developing at the first investigation because the bleeding had already ceased*

## *Tortuosity of the Vessels*

There was a greater incidence of tortuous vessels in those stumps exhibiting a high degree of vascular richness They were noted in the main trunks and also peripheral branches of both arteries and veins This phenomenon was most pronounced in the peripheral vessels which often showed spiral shaped (corkscrew) formation The tortuous vessels were observed most often in rabbits investigated 3–4 weeks after the amputation

## *Haematoma*

The development of haematomas was studied in animals whose vascular systems had been filled with thorotrast immediately before the amputation A small haematoma arose rapidly in the soft tissues in the distal region of the stump and could be seen owing to the fact



*Figure 5 Two weeks after amputation the stump shows increased vascularization with an abundance of small tortuous vessels*

that the blood was mixed with contrast medium (Figures 1 and 2) The haematoma continued to develop and after 3 days was relatively extensive (Figure 3) In some of the animals which had been injected with contrast medium shortly after the amputation some of the vessels were seen to have separated which as far as could be judged had been caused by the haematoma

## *Bone Changes*

A reformation of the distal bone end took place The first sign of this was an increasedly dense zone immediately around the distal bone end After 3 weeks a spur had developed at this site in all of the animals (Figures 6 7 and 8) The shape and site of the spur formation corresponded to a certain degree to the position of the stump haematoma which was present at an earlier stage



*Figure 6 A stump investigated 3 weeks after amputation A spur has developed and is surrounded by a large number of vessels*



*Figure 7 A stump investigated 4 weeks after amputation Note the marked spur formation*



*Figure 8 A stump investigated 4 months after amputation A spur has developed and the vascularization in the stump is markedly increased*

## DISCUSSION

The trauma which the amputation involves appears to lead to an immediate but transient decrease in the diameter of the arteries and probably also the veins. This may possibly be explained by an arterial spasm and vein spasm provoked reflectorically. *Kinmonth, Rob & Simeone* (1962) state that spasm may be either segmental or general involving large proportions of a major artery after trauma. The incidence of arterial spasm among casualties is not known, however. Furthermore, swelling occurs in the stump due to tissue oedema and haematoma and this may also possibly contribute to decreased vascular diameters in the first period of the post-operative phase.

The haematoma may develop rapidly after the amputation and become relatively extensive. The bleeding arises mainly from the medullary canal but also of course from other damaged tissue.

Within 2–3 days a new phase arises in the circulatory conditions in the stump when dilation of the arteries and veins takes place. This is an expression of increased blood flow in the traumatized region.

This vascular process continues to develop and appears to reach its maximum in 3–4 weeks. By this time during the healing stage of the stump there is pronounced hypervascularization with a high degree of further vascular changes, namely tortuosity of arteries and veins.

*Hulth & Olerud* (1962) on studying the recovery process in the amputation stump observed the development of both periosteal and endosteal callus. Abundant vascularization was demonstrated with microangiographic methods.

In the present study this callus formation was confirmed. It was expressed as a spur-like formation which became visible after 3–4 weeks. Around this spur there was pronounced hypervascularization which has been described previously.

The spur occurs at the site of the haematoma which thus seems to *participate in its development. It is possible that a part of the* haematoma is transformed to an osteoid tissue which in turn develops into the osseous spur.

On repeated thorotrast injections an accumulation of thorotrast was sometimes seen in the stumps, mostly within the boundaries of the haematoma. This may indicate that thorotrast can be taken up by phagocytosing cells in the haematoma. This phenomenon was not *studied closely in this investigation, however.*

## SUMMARY

15 rabbits were investigated angiographically immediately before and after leg amputation

The investigation showed vascular and bone changes which occurred either immediately after or a short time after the amputation

Immediately after the amputation the arterial diameter appears to decrease After 2–3 days however the vascularization begins to increase and when this is at its most pronounced stage an abundance of tortuous vessels is seen These develop further and at the same time a spur formation arises on the bone stump A possible cause of this spur is the post-operative haematoma which during its different phases of development may also conceivably influence the vascular development

## RESUME

15 lapins ont eté examines angiographiquement immediatement avant et apres une amputation de la patte

Les examens ont montre des modifications vasculaires et osseuses qui apparaissent immédiatement ou tres peu de temps apres l amputation Immediatement apres l amputation le diametre arteriel semble diminuer Apres 2–3 jours cependant la vascularisation commence a augmenter et quand elle est au stade le plus prononce on voit une abondance de vaisseaux tortueux Ceux-ci se developpent encore et il se forme simultanement un eperon sur le moignon La cause possible de la formation de cet eperon est l hematome post operatoire qui dans ses differentes phases de developpement a peut-etre une influence sur le développement vasculaire

## ZUSAMMENFASSUNG

15 Kaninchen wurde unmittelbar vor und nach einer Beinamputation angiographisch untersucht

Die Untersuchung zeight Gefäss und Knochenveränderungen die unmittelbar oder eine kurze Zeit nach der Amputation auftraten

Unmittelbar nach der Amputation scheint der arterielle Durchmesser abzunehmen Nach 2–3 Tagen jedoch beginnt die Gefässversorgung zuzunehmen und wenn dieser Zustand am ausgesprochensten ist sieht man einen Uberfluss von gewundenen Gefässen Diese entwickeln sich weiterhin und zu gleicher Zeit entsteht eine Sporenbildung am

Knochenstumpf Eine mögliche Ursache dieses Sporens ist das post operative Hämatom das während der verschiedenen Phasen seiner Entwicklung möglicherweise auch die Gefässentwicklung beeinflusst

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# FACTORS AFFECTING THE DETERMINATION OF THE PHYSICAL PROPERTIES OF FEMORAL CORTICAL BONE[1]

By

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Received 16 IX 65

Many methods have been used for the preparation storage and testing of samples in the determination of the physical properties of bone (1 3 9) The methods and conditions have varied or are sometimes inadequately described so that it becomes difficult to compare the works of various authors The desire to provide a standard method of preparation storage and testing of bone specimens furnished the framework of this study Here a summary is presented of the interim results of a continuing investigation of the physical properties of the human femoral cortex obtained from autopsy material Some of the general mechanics terms used in the text are summarized in Appendix 1

## MATERIAL AND METHODS

The entire mid femoral diaphysis from twenty adult subjects was removed at routine post mortem examination that was performed on the day of death or the day after The segments were 15 cm long and began 5 cm distal to the base of the lesser trochanter After removal the segments were worked in the fresh state or stored at —20 C in Ringers solution until they could be handled

The general method of reduction of the segments to test size is as follows It is placed in Ringer s solution at room temperature and it is kept in Ringer s solution at all times when it is not actively being handled It is first sectioned, in its long axis with a handsaw or a bandsaw under a constant cold aqueous drip Excess

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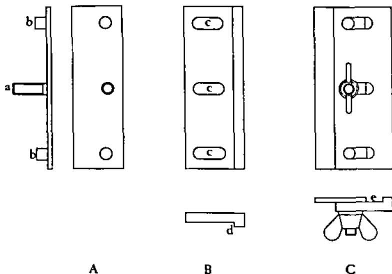



*Figure 1 Several views of apparatus used to make rectangular segments of bone*
*A Top and lateral view of adjustable plate showing screw stud (a) and excursion control studs (b)*
*B Similar views of base plate showing grooves for screw and excursion studs (c) and height control bar (d)*
*C Top and lateral views of assembled apparatus showing slot (e) for placing of bone specimen*
*The rough sextant or octant of bone is placed in slot and then secured by means of the wing nut It is then ground with repeated turning of 180 until flush with the apparatus This produces one dimension The specimen can then be shifted to another apparatus for producing a different si e in the right angle pair of sides or worked in the same apparatus if square sides are desired The apparatus should be made of very hard steel to reduce wear When wear becomes apparent the plate and height control bar can be replaced with little difficulty*

heat production is thereby diminished The number of longitudinal strips and their size is varied according to the needs of the specific experiment It is usually possible to obtain 15 strips which are then labelled according to the quadrant of origin and placed in Ringer s solution These strips can then be further reduced in size by sawing The total number of final specimens that can be obtained varies with the desired length and thickness The strips are then placed in a special holding tool (Figure 1) and ground under cold water using water proof silicon carbide paper or a universal drill fitted for grinding at low speeds In practice the drill is used for rough shaping of the specimen and manual grinding for final shaping The specimens are repeatedly turned during the grinding process to insure mutually flat and perpendicular sides and care is taken so that bone from the center of the cortex remains after the grinding process With the use of holding tools of various sizes we can prepare specimens from 0 5 mm × 1 0 mm to 5 × 15 mm in cross section dimensions the major limitation being the thickness of the cortex Specimens with greater than 1 5 per cent variation in cross section dimen

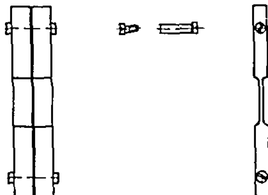


*Figure 2 Diagram of side and front view and screw assembly of apparatus used to reduce central area of specimen A specimen is prepared of desired dimensions A typical specimens in this study is 5 mm broad 2 mm thick and 50 mm long This small plank is placed in the slot of the apparatus and screws are tightened It is then mounted in a vice under a cold aqueous drip and with a tempered file the central area is reduced until it is flush with the reduced central portion of the apparatus The apparatus can be made of varying sizes to accommodate specimens of different thickness or length As in previously shown apparatus it must be made of very hard steel*

sions throughout their length are discarded or reworked If a specimen is to be tested in tension until failure the central area is reduced by the use of a holding tool of the type shown in Figure 2 The method is rapid simple and requires little experience to acquire the ability to produce precise specimens

After the specimen preparations are completed the measurements of the cross section dimensions are performed with a CEJ friction release micrometer with an accuracy of 0 005 mm After the measurements are completed the specimen is ready for testing Microscopic examination of undecalcified cross sections of 50 specimens indicated that a normal complement of osteocyte nuclei was present and the staining pattern was normal Accordingly it is felt that the method of preparation had not had a deleterious effect on the bone

Bending tension and compression tests are performed on an Instron TT CM floor model tensile test machine that permits simultaneous recording of the load being applied and deformation produced with an accuracy of ± 0 5 per cent (14) It is calibrated before each test run for accuracy of load recording recorder speed and excursion of the load heads Load is determined from the recorder tracing and deformation either calculated from the tracing or read directly from the machine Special jaws fitted with silicon carbide paper enable specimens for tension testing to be held without detectable slippage Bending specimens can be subjected to bending load either as a cantilever or doubly supported beam with central or eccentric load via a special head for the machine which has been designed to function as a clasimeter or cantilever load support Compression tests are performed with the standard Instron Compression Cage All tests are performed in a room with controlled temperature and humidity at 21 C ± 1 and 66 per cent ± 2 per cent respec

tively Bending tests are performed submerged in Ringer s solution under controlled temperature via a cyclotherm pump Compression and tension tests are performed in air Prior to testing all specimens are warmed to 37 C in Ringer s solution for one hour unless the specific requirements of the test dictate room temperature and hydration A specimen for bending can be pla ed on its supports in fifteen seconds as can the compression specimens Tension specimens require approximately three minutes for this procedure Unless otherwise stated all tests indicated in the text are bending tests to failure performed with end supports unfixed, and progressive central load with a rate of deformation 1 cm/minute at 37 C in Ringer s solution The formulae used for calculation of the physical properties are presented in Appendix ?

Standard statistical methods were utilized in evaluating results (20) The 5 per cent level of probability was chosen as the criterion of statistical significance

## EXPERIMENTS

The problems that have been investigated are presented here in the form of specific questions with each experiment being detailed as the question is presented

### *Is there any Difference between Testing at Body Temperature and at room temperature?*

Seventy seven specimens from three subjects were divided into two groups and closely matched as regards quadrant of origin One group was tested at 37 C and the other at 21 C No significant differences were noted relative to maximum stress and energy absorbed to failure The modulus of elasticity was 5 per cent higher in one of the subjects at room temperature and unchanged in the others A significant 6 per cent increase in total deflection to failure was noted in the group tested at 37 C These findings coupled with the observation of *Smith & Walmsley* (19) has led us to adopt 37 C as a standard temperature condition when the requirements of the test permit

### *What is the Effect of Short term Air Drying on the Physical Properties?*

One hundred thirty seven specimens from five subjects were studied These as previously were closely matched as regards site of origin All tests were performed at room temperature without previous warming to body temperature Small groups were tested under Ringer s solution and at varying times in air ranging from five minutes to one hour One group was dried in an incubator at 105 C for one week and then tested

The results showed that after ten minutes in air specimens from

some of the subjects began to show increase in strength an effect which was general after fifteen minutes and pronounced in one hour

The average value for maximum stress in specimens tested under Ringer's solution was 19 3 kg/mm whereas those specimens tested after one hour in air had an average value of 23 1 kg mm This was significant beyond the 1 per cent level After 30 minutes in air the differences in values were of borderline significance (0 10 > P > 0 05) Energy absorbed to failure increased after drying but the degree of change was not statistically significant The modulus of elasticity showed no change associated with air drying up to one hour Since this observation appears to be incompatible with the above it is being investigated further

The specimens from three subjects that had been incubated for one week prior to testing when compared to wet tests from the same subjects showed that there was no significant change in maximum stress the modulus of elasticity increased significantly and energy absorbed to failure and total deflection decreased significantly

There may be a decrease in the rapidity to the effect of air drying if the specimens are made larger In order to circumvent the problem it was decided to test under fluid or as quickly after removal from fluid as possible

*Does Free ing Prior to Testing Produce any Effect upon the Physical Properties?*

Seventy four specimens from three subjects were prepared as rapidly as possible following the obtaining of bone from autopsy One-half were tested approximately three hours after removal from the body and the others were placed in a deep freeze at —20 C for three four weeks and tested after thawing There was a 5 per cent increase in the average strength of the samples that had been frozen from 16 7 kg mm to 17 6 which was not significant and no change in any of the other parameters mentioned These results coupled with Frankel's observations on intact femurs lead us to feel that we do not significantly change the physical properties by prior freezing if the specimen is adequately hydrated and thawed before testing (10)

*What is the Effect of Fixation of the Specimen in Formalin?*

Fifteen specimens from one subject were prepared fresh and then progressively loaded in tension at 0 1 cm minute to 8–9 kg such loads being well below those required to produce permanent deformation

as demonstrated by additional tests to failure of specimens from the same subject After the initial test the specimens were placed in 10 per cent formalin solution for three weeks and then retested The modulus of elasticity was determined in both instances and no significant change was noted There is disagreement relative to the effect of formaldehyde fixation of specimens (2 7 15) and although the findings of this experiment are in agreement with those of *McElhaney* (15) relative to the modulus of elasticity it is felt that whenever possible bone should be tested in the unfixed state

*With small Specimen Testing is there any Effect that can be Attributed to varying the Specimen Size?*

Thirty specimens 1 5 × 1 0 × 30 mm were compared to 70 2 × 2 × 30 mm specimens from the same subjects No significant differences were noted in any physical property that could be attributed to this variate However since errors in tolerance and measurement are absolutes their relative importance increase as the specimens are made smaller One must therefore balance this consideration against the desire to obtain a large number of specimens from any one subject

*What are the Changes in Cross section Dimensions of the Specimen due to Testing?*

This question is necessitated by the fact that it is usually more convenient to measure the dimensions after it has been tested than before since there is some urgency involved in measuring the sample when one desires to test it as rapidly as possible following removal from the body This is coupled with the fact that a change in dimensions occurs in isotropic materials during testing and after tests are completed (16) Thus if one uses the initial cross section measurements in the calculations of maximum stress the value will differ from that obtained utilizing the measurements obtained after failure Seventy specimens 2 × 2 mm in cross section dimensions were marked at their mid point measured and then loaded to failure on the mark They were then remeasured as close as possible to the mark There was on average a 2 per cent decrease in the cross section area near the fracture site after testing which was not significant or consistent but more important splintering occurred in a sufficiently large number of cases to make adequate measurement near the fracture impossible Accordingly in bending tests we measure mark and load on the mark

In specimens that are to be tested in tension it is impossible to predict the exact location of the fracture in the test area so that a comparative experiment such as the above cannot be performed. We have adopted the following procedure. Five pairs of measurements are made from one end of the filet to the other at equally spaced intervals and marked accordingly. If the specimen fails on a mark, the appropriate measurement is utilized in the calculations. If it fails between a pair of marks, the average is used for the calculations. This method is used since it is not known how much of the waisting that occurs in a tension test will recover immediately after failure, thus preventing the observer from knowing whether he is calculating the engineering stress, true stress, or some value between the two.

Specimens that are tested in compression present no problem since when they fail it is often by a type of fracture that leaves little to measure. The dimensions are determined beforehand.

*What is the Effect of varying the Distance between Supports in Bending Bone as an End supported Beam?*

In isotropic materials the strength and modulus of elasticity vary with the distance between supports when being bent as end supported beam (17). Shear stresses increase in loading of very short beams (17). Eight specimens from two subjects $2 \times 2 \times 60$ mm were measured at their mid point and then loaded up to one kg six times with 15 minutes between each loading. The distance between supports was changed between each loading from a ratio of 6:1 (Distance: thickness of specimens) initially to ratios of 10, 15, 20, 25 and 30:1. Between loading the specimens were kept in Ringer's solution at 37° C. It was found that there was a significant decrease in the modulus of elasticity with ratios less than 15:1 and a slight decrease with the ratio of 30:1. There was essentially no difference between the ratios of 15, 20 and 25:1. We customarily use the 15:1 ratio in testing since with thicker specimens (3 or 4 mm in thickness) this decreases the length requirement.

*What is the Effect of Repeated Loading on the same Specimen?*

Thirty specimens from three subjects were tested in the following manner. The approximate breaking strength was determined for the specimens of each subject by loading three extra specimens to failure. A load was then selected for each subject that was approximately 35 per cent of the breaking load. The selected load was applied to the

specimens from a subject two or three times with at least one minute intervals between the removal of the load and its reapplication The modulus of elasticity was calculated for each case of loading and no significant differences were noted between first second or third trials This should not be interpreted to mean that repetitive loading does not effect the physical properties Currently we are engaged in the determination of the number of repeat applications of a static load that can safely be undertaken before an effect is demonstrated

*What is the Effect of the Rate of Deformation upon the Physical Properties?*

In a series of compression tests *McElhaney* (16) showed that the modulus of elasticity and strength of human and bovine bone vary with the rate of strain Our experiments relative to this question are as follows Twelve specimens from one subject 2 × 2 × 50 mm were loaded progressively as a cantilever to 250 grams at a rate of 0 1 cm/minute The load was released and two minutes were allowed to elapse The specimens were then reloaded to 250 grams this time at a rate of 1 0 cm/minute The position of each specimen was not changed between loadings and the test conditions relative to temperature and hydration were constant at 37 and submerged The modulus of elasticity was calculated for each instance and an average increase of 7 6 per cent was found for the more rapid loading rate This difference was highly significant ($p < 0\ 001$)

Further tests using 6 tension specimens and 5 bending specimens loaded centrally as a supported beam substantiated the finding that modulus of elasticity increase with a more rapid rate of deformation It thus becomes necessary to accompany all data presentations relative to physical properties with information relative to the deformation rate There is at present insufficient data in the current study or that cited to determine the exact relationship between the modulus of elasticity and the rate of deformation

*Is there any Difference in Physical Properties that can be Accounted for by Quadrant of Origin within the Femoral Shaft?*

Evans has shown that significant differences can be demonstrated between the physical properties of different bones and separated regions of the same bone (7 9) All specimens in this study came from near identical sites in the femoral mid shaft and all specimens were coded from the standpoint of quadrant of origin (posterior lateral

etc.) at the beginning of the study. The data from thirteen subjects was analyzed with regard to this variate. It was found that the lateral quadrant specimens were strongest (19.3 kg/mm) and posterior weakest (17.8 kg/mm) with anterior and medial being second and third respectively (18.9 & 18.7). These differences were significant ($P < 0.01$) and the ranking was fairly consistent, *i.e.* the lateral quadrant specimens were strongest in 6 of the subjects and the posterior weakest in 8 (Coefficient of concordance = 0.30). The values for the medial quadrant closely approximated the mean value for a subject in most instances. Therefore if large numbers of specimens cannot be tested or one cannot obtain the entire segment of diaphysis, the medial quadrant appears to be the best choice to obtain a valid idea of the properties of the mid femoral diaphysis.

### *Can the Variation in Physical Properties be Accounted for by Features of the Microscopic Anatomy?*

Undecalcified cross sections of 125 wet tested specimens were prepared on either side of the fracture site as close to the fracture as possible by a modification of Frost's method and then stained with 1 per cent basic fuchsin for at least 48 hours (11, 12). The first 50 sections to be completed were measured with an eyepiece micrometer at low magnification and the measurements compared to the previously recorded measurements for the specimens prior to sectioning. No differences were noted, indicating that shrinkage during preparation and mounting was nil.

All sections from the 125 specimens were examined at 320 × magnification utilizing a Zeiss I integrating eyepiece and completely scanned several times and the volume of the specimen occupied by Haversian canals determined (13, 18). This volume varied from 2 per cent to 16 per cent in different specimens. No correlation was noted between the volume and maximum stress, total strain, energy absorbed to failure and yield time. There was a low grade correlation with the modulus of elasticity. The findings agreed in part with those reported by *Vose* (21) and *Evans* (8).

Do these findings indicate that the microscopic anatomy cannot account for the variations? Not necessarily. It is probable that the arrangement of the Haversian systems within the specimen is more important than is the total volume or number of canals. In order to explain this assumption, it is necessary to digress.

*Table 1 Some physical properties*

Data for some physical properties of femoral cortex in specimens from 14 subjects tes progressive central load at a rate of 1 0 cm/minute at 37 in Ringer s solution Tens loaded progressively

| Case | Age Sex | Cause of Death | Maximum Stress kg/mm Bending | Tension |
|---|---|---|---|---|
| I | 34 M | Suffocation | 19 6 ± 1 9§ | 8 0 |
| II | 34 M | Myocardial Infarction | 17 9 | 8 9 |
| III | 41 F | Carcinomatosis | 20 6 ± 3 5 | |
| IV | 46 F | Myelomatosis | 21 2 ± 1 9 | |
| V | 47 F | *Melanoma* | 17 5 ± 1 0 | |
| VI | 55 M | Pneumonia | 19 0 ± 2 1 | |
| VII | 57 M | Hepatoma | 18 7 ± 1 9 | |
| VIII | 62 M | Pneumonia | 19 7 ± 1 6 | 9 9 ± 1.5 |
| IX | 67 M | Trauma | 20 3 ± 2 7 | 8.3 ± 1 6 |
| X | 69 M | Myocardial Infarction | 17 6 ± 1 3 | 8 3 |
| XI | 74 F | Myocardial Infarction | 18 8 ± 1 3 | |
| XII | 76 M | C V A | 21 3 ± 3 3 | 9 5 |
| *XIII* | 77 M | *Abdominal Abscess* | *11 7 ± 1 4* | |
| XIV | 91 M | Myocardial Infarction | 13 9 ± 3 4 | |

§ One Standard Deviation Standard Deviations were not calculated for groups smal

In the calculation of the moments of inertia in this study an homogenous material is assumed although this is obviously not the case in bone In order to calculate a true moment of inertia for a porous material the moment of inertia of each void (Haversian Canals in this instance) in relation to the axis of loading must be determined and the combined moments for all of the voids subtracted from the moment assumed from the outer dimensions and shape of the specimen

The above refers to calculation of the physical properties in bending tests In tension testing it is assumed that stress is homogenous throughout the length of the test area This can only be true if the Haversian canals are homogenously dispersed throughout the test area which is not the case in small samples of bone In addition the presence of a canal at the surface of the specimen will lead to an increase in stress at that point and may cause failure (9) So at best one only has an estimate of the stress at the site of failure or throughout the lenght of the filet

It has been indicated that there is no correlation between Haversian

*fresh samples of mid femoral cortex*
in the wet warm state Bending tests were performed with unfixed end support and tests were performed in air immediately after removal from 37 Ringer s solution and a rate of 0 1 cm/minute

| Modulus of Elasticity kg/mm × 1000 | | Energy Absorbed To Failure kg M c/mm³ × 10³ | | Number Samples | |
|---|---|---|---|---|---|
| Bending | Tension | Bending | Tension | Bending | Tension |
| 1 58 ± 16 | 72 | 4 58 ± 1 03 | 14 2 | 46 | 8 |
| 1 58 | 58 | 2 98 | 12 9 | 4 | 4 |
| 1 77 ± .30 | | 5 29 ± 1 74 | | 20 | |
| 1 97 ± 30 | | 4 46 ± 1.36 | | 22 | |
| 1 41 ± 16 | | 4 63 ± 91 | | 29 | |
| 1.57 | | 3 06 ± 95 | | 12 | |
| 1 69 ± 19 | | 3 64 ± 91 | | 20 | |
| 1 63 ± 17 | 66 ± 12 | 4 01 ± 87 | 18 9 ± 5 7 | 36 | 16 |
| 1 71 ± 22 | 67 ± 08 | 4 55 ± 1 86 | 11 0 ± 4 3 | 27 | 10 |
| 1 44 ± 15 | 53 | 3 84 ± 50 | 14 9 | 19 | 9 |
| 1 68 ± 12 | | 3 60 ± 95 | | 24 | |
| 1 77 ± 30 | 45 | 5 50 ± 1 57 | 17 7 | 28 | 5 |
| 1 06 ± 15 | | 2 19 ± 45 | | 14 | |
| 1 30 ± 29 | | 2 89 ± 1 32 | | 19 | |
| | | | | 318 | 52 |

than 10 Specimens from both femurs are included in the data

canal volume and the physical properties This is true in the relation to specimens that have a canal volume of 4–10 per cent (80 per cent of the total number examined) but in the extremes *i e* very dense or very porous specimens one could predict corresponding changes in strength and modulus of elasticity

Thus the data lead to the conclusion that in order to account for the physical properties of wet bone on a microscopic basis one must be prepared to reconstruct the three dimensional microanatomy of the of the specimen in the large majority of instances

## DISCUSSION

Since bone is an heterogenous or anisotropic material (4 5 6 7) the laws that are applied to homogenous materials should be used with caution if at all We have used standard formulae for our calculations for the sole purpose of comparing the effects of the various factors cited but with the complete understanding that the values obtained may

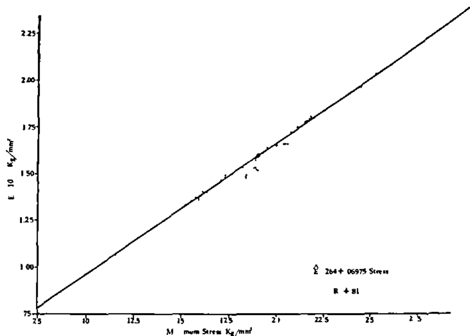



*Figure 3 A scatter diagram depicting the relation between maximum stress and the modulus of elasticity in 318 wet tested specimens that were end supported and centrally loaded at a rate of 1 cm/minute until failure The line is the least squares best fit to the data for the estimate of modulus of Flasticity from maximum stress The grand mean for both variates is indicated by the circle The standard error of the estimate for the modulus of elasticity is 15 For the estimation of maximum stress modulus of elasticity the following equation should be used where $\hat{\sigma}$= estimated maximum stress*

$$\hat{\sigma} = 4\,0 + 9\,45E$$

*The standard error of the estimate is 1 8 kg/mm*

not indicate the true properties of bone The formulae utilized are presented in Appendix 2

With these considerations borne in mind the data in Table 1 can be evaluated from the standpoint of comparison of subjects These data represent the findings on specimens that were subjected to identical type of loading under identical conditions It can be seen that there is no consistent pattern as regards age The differences between individuals in maximum stress and modulus of elasticity are highly significant as are the differences between the findings in tension and bending Energy values are of borderline significance The differences between tension and bending values from the same subjcts may in part be accounted

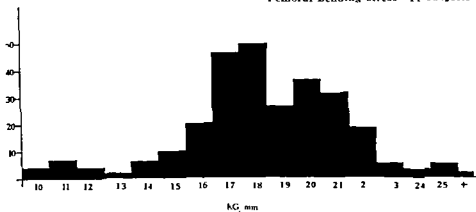



*Figure 4 A Histogram showing the overall distribution of maximum stress in bending values in 14 subjects It is felt that the relative decrease in the number of values at 19± 5 kg/mm is a chance occurrence due to the relatively few total number of subjects providing samples and does not lessen the overall normal character of the distribution*

for by the difference in the rate of deformation of the specimens but there is undoubtedly a real difference in the axis of loading that cannot be accounted for by rate

In the bending specimens that were tested wet a high correlation was present between the maximum stress and modulus of elasticity (R = + 81 P < 001) (Figure 3) An even higher correlation was noted when average values for subjects were compared (R = + 95 01 > P > 001) A similar comparison of the findings in the tension specimens demonstrated a much lowed correlation (R = + .27 10 > P > 05) in the individual samples Thus in bending one can estimate one property if the other is known and the appropriate equations are presented in Figure 3 This finding is in agreement with data for rat bone reported by *Weir et al* (22) The overall distribution of physical properties in this group of adult human femoral samples is of the normal slightly skewed type as is seen in Figure 4

Certain statistical problems are present in the comparative type of experiments that were performed These have as their basis the heterogeneity of bone so that some variation in the properties is found if specimens are made from sites as close as 1 mm from each other Thus if one wished to determine the effect of one or another variate upon the ultimate strength of samples a small real difference in results might not be of statistical significance unless an inordinate number of com

*parisons are made This problem can be circumvented in part by performing* tests and determining properties that enable one to use the same specimens several times but it cannot be eliminated completely

## SUMMARY AND CONCLUSIONS

1 Values for physical properties calculated utilizing standard formulae were used as a basis of comparison of specimens that were prepared and loaded in identical fashion

2 More than 500 specimens from mid femoral diaphysis from 20 subjects were tested either in bending tension or compression

3 It was found that

a) There was no significant effect of temperature on maximum stress and energy absorbed to failure in the range between 21 C and 37 C The modulus of elasticity may be slightly increased Total deflection to failure is increased at 37 C

b) Air drying alters the physical properties in less than one hour in the majority of instances

c) Freezing of specimens prior to testing increases the strength of specimens insignificantly but does not change any other property

d) Fixation in formalin does not appear to alter the modulus of elasticity of small samples

e) There is no difference in physical properties that can be attributed to size of specimen in the size ranges tested

f) When bending bone as a beam with central load and unfixed end supports the modulus of elasticity can be significantly changed by varying the distance between supports

g) The cross section dimensions of specimens should be measured before testing whenever possible

h) Repeated loading of the same specimen does not alter the modulus of elasticity if loads of the order of 35 per cent of the breaking strength are used and one minute or more is allowed for recovery

i) Specimens obtained from the lateral quadrant of the midfemoral diaphysis are stronger and those from the posterior quadrant are weaker with anterior and medial quadrants intermediate on average

j) Determination of the volume of Haversian Canals in the specimen does *not* account for the bulk of the variation in the physical properties in individual specimens

k) Significant differences exist in the physical properties of bone from different individuals that are not accounted for by age

l) A high correlation is present between the maximum stress in bending and the modulus of elasticity in bending

4 Bending tests of small samples of cortical bone appear to be reliable in the demonstration of differences in physical properties between individuals

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RESUME

1 Il a ete utilisé une formule standard pour calculer les valeurs des proprietes physiques comme base de comparaison pour des speci mens prepares et charges de maniere identique

2 Plus de 500 specimens de la diaphyse mi femorale provenant de 20 sujets ont ete soumis a des epreuves de flexion tension ou com pression

3 Il a ete prouvé que

a) la temperature n a pas d effet apparent en cas d effort maximum et d energie absorbee jusqu a limite de rupture dans l intervalle entre 21 et 37 C Le module d elasticite peut s accroite legerement La de flexion totale jusqu a limite de rupture est accrue a 37 C

b) La secheresse de l air altere les proprietes physiques en moins d une heure dans la majorite des cas

c) La congelation des specimens avant l epreuve accroit la force des specimens d une maniere insignifiante mais ne modifie aucune autre propriete

d) La fixation dans la formaline ne semble pas alterer le module de l elasticite des petits echantillons

e) Il n y a pas difference dans les propriétes physiques qui puisse etre attribuee a la dimension des specimens dans la rangee des dimen sions mises a l epreuve

f) Lorsque l os est ploye comme une poutre avec une charge centrale et des supports non fixes aux extremites le module de l elasticité peut changer d une maniere sensible si l on varie la distance entre les sup ports

g) Les dimensions de la section en croix des spécimens doivent etre mesurees avant l épreuve lorsque cela est possible

h) Une charge repetée sur le meme specimen n altere pas le module de l elasticite si des charges de l ordre de 35 per cent de la force de rupture sont utilisees et qu il s ecoule une minute ou plus pour recuperer entre les charges

i) Les specimens obtenus du quadrant lateral de la diaphyse mi femorale sont plus forts et ceux du quadrant posterieur sont plus faibles les quadrants anterieur et medial etant dans la moyenne intermediaire

j) La determination du volume des canaux de Havers dans le specimen ne compte *pas* pour l ensemble des variations des proprietes physiques des specimens chez les differents sujets

k) des differences sensibles qui ne sont pas dues a l age existent dans les propriétes physiques des os provenant de sujets differents

l) Il existe une étroite correlation entre l effort maximum en flexion et le module de l elasticite en flexion

4 Les epreuves de flexion de petits echantillons d os cortical semblent plus sures pour la demonstration des differences des proprietes physiques chez les differents sujets

## ZUSAMMENFASSUNG

1 Werte fur physikalische Eigenschaften die mittels der Verwendung von Standardformeln errechnet waren wurden als eine Vergleichbasis von Proben die in identischer Weise praparıert und belastet waren gebraucht

2 Mehr als 500 Proben der mittleren Femurdiaphyse von 20 Verstorbenen wurden entweder durch Beugung Spannung oder Druck geprüft

3 Es wurde gefunden dass

a) die Temperatur keinen entscheidenden Einfluss auf die maximale Belastungsfahigkeit oder auf die absorbierte Energie im Bereich zwischen 21 und 37 C hat Der Modulus der Elastizitat mag leicht gesteigert sein Das totale Biegungsvermogen bis zum Bruch ist bei 37 C erhoht

b) Lufttrocknung verandert die physikalischen Eigenschaften in weniger als einer Stunde in der Mehrzahl der Fälle

c) Einfrieren der Proben vor der Prufung vermehrt die Stärke der Probe unbedeutend verändert aber keine andere Eigenschaft

d) Fixierung in Formalin scheint den Elastizitetsmodulus von kleinen Proben nicht zu verandern

e) Es besteht kein Unterschied von physikalischen Eigenschaften welcher der Grosse der Proben in den gepruften Grossenbereichen zu geschrieben werden kann

f) Wenn man Knochen wie einen Balken mit zentraler Belastung und beweglischen Endunterlagen biegt dann kann der Elastizitäts modulus mittels Verschiebung der Distanzen zwischen den Unterstüt zungspunkten bedeutend verändert werden

g) Die Querschnittsgrössen von Proben sollten womoglich vor der Prufung gemessen werden

h) Wiederholte Belastung derselben Probe verandert nicht den Elastizitätsmodulus wenn eine Belastung die 35 Prozent der Brechungs starke entspricht verwendet wird und eine Minute oder mehr zwischen den Belastungen verstreichen darf

i) Proben die vom lateralen Quadranten der mittleren Femur Diaphyse erhalten werden sind stärker und die vom hinteren Qua dranten sind schwächer während die vorderen und medialen Qua dranten dazwischenliegende Werte zeigen

j) Bestimmung des Volumens der Haversschen Kanäle am Präparat gibt *keinen* Wertmesser fur die Grösse der Variationen von physika lischen Eigenschaften der einzelnen Proben

k) Der Knochen verschiedener Individuen weist bedeutsame Ver schiedheiten der physikalischen Eigenschaften auf die nicht auf das Alter zuruckzufuhren sind

l) Es besteht eine ausgesprochene Wechselwirkung zwischen der grossten Biegungsbelastung und dem Elastizitätsmodulus beim Biegen

4 Biegungsprufungen von kleinen Proben kortikalen Knochens scheinen verlässlich zu sein um die Verschiedenheiten physikalischer Eigenschaften zwischen Individuen aufzuzeigen

## APPENDIX 1

### *Definition of terms used in the text*

*Force*—Anything that tends to change a body with respect to its state of motion or the relative position of its molecular structure The three basic types of forces are compression tension and shear (a push a pull or a twist) all other forces repr senting these in combination

*Stress*—The intermolecular resistance within a body to force It is a computed quantity expre sed in psi kg/mm or dynes/cm If the original cross section area is utilized in the calculations a value called the engineering stress is obtained If the cro s section area during application of the load is used the value is called the *true stress* As indicated in the text the dimensions determined during loading or after failure may be erroneous and in addition there is real question concerning the

validity of the true stress concept. All calculations in this study are based on original cross section dimensions.

*Strain.*—The forced change in dimensions or form of a body due to stress. A stretch is a tensile strain, a shortening is a compressive strain, an angular distortion is a shear strain. Commonly the term strain is used synonymously with the term *unit strain* which is the elongation or shortening per unit length or change in angles between two lines originally at right angles to each other.

*Deformation.*—The term is used synonymously with strain here.

*Modulus of elasticity.*—The rate of change of unit stress with hespect tto unit strain for the condition of uniaxial stress within the proportional limit.

*Proportional limit.*—The greatest stress which a material can sustain without deviating from the law of stress strain proportionality.

*Energy absorption.*—The work that is done per unit volume. In this report the energy absorbed to failure or energy of rupture has been calculated.

*Moment of Inertia.*—A porperty of a plane area based upon its form that indicates its resistance to torque or bending forces.

*Isotropic.*—In this presentation, a material that has the same properties in all directions, *i.e. strength, modulus or elasticity.*

*Strength.*—The limit to which a material can be strained. Here it is used synonymously with the ultimate stress/unit area.

## APPENDIX 2

*Formulae used in calculation of the physical properties presented in the text*

Notation

$\sigma$ = Stress at failure
$e_u$ = Unit strain
P = Load
I = Moment of Inertia
E = Modulus of Elasticity
$L_0$ = Original Length of Specimen or test area
$L_1$ = Length of specimen at any point in loading
M = Maximum Moment
A = Cross section area of specimen or test area
B = Breadth of specimen
D = Depth of specimen
c = Distance from neutral axis of greatest fiber stress
y = Maximum deflection in bending

*Bending*

$$M = \frac{PL}{4} \text{ (supported Beam)} \qquad c = \frac{D}{2} \qquad M = PL \text{ Cantilever}$$

$$\sigma = \frac{M}{I/c} = \frac{PL/4}{BD^3/12} \times 2/D = \frac{3/2\,PL}{BD}$$

or as a cantilever

$$= \frac{PL}{BD^3/12 \times 2/D} = \frac{6PL}{BD}$$

$F = \frac{PL^3}{48I}$ or for a cantilever $\frac{PL^3}{3I}$

Tension

$\sigma = P/l$

$E = \frac{P/l}{\varepsilon_t}$ where P and $\varepsilon$ measured from most nearly linear portion of curve

Energy absorbed to failure is calculated from the area under a stress strain curve utilizing a factor derived from the rate of deformation size of load speed of recorder and the volume of the specimen

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# EHLERS DANLOS SYNDROME

*A case with some skeletal changes*

*By*

SIVERT SVANE

Received 23 IV 65

The Ehlers Danlos syndrome (hereafter referred to as E D) is an inherited systemic tissue disorder presenting several interesting features even to the orthopedic surgeon It is primarily characterized by the triade 1) hyperelasticity of skin 2) increased fragility of skin and blood vessels and 3) increased laxity and mobility of joints Several other symptoms may occur Cases are reported where the syndrome is incomplete or even subclinical These *formes frustes* may be very confusing to the clinician (*Johnson & Falls* 1949 *Leider* 1949 *Broberger Eriksson & Wedin* 1959)

A detailed survey of the various manifestations of the disease will be found in *McKusick*s comprehensive study (1960) hence only a short general survey will be given below

*McKusick* on going through the literature found approximately 100 cases of E D but the disease is certainly more frequent than this number indicates Apart from Ehlers original report (1901) the Scandinavian literature comprises papers by *Haxthausen* (1936) *Strandberg* (1938) *Wigers* (1950) *Huseby* (1925) *Kornstad* (1953) *Sæmundson* (1956) and *Broberger et al* (1959)

The fundamental defect in this connective tissue disorder remains controversial It is probably due to a *collagen* defect *Jansen* (1955) has advanced the theory that E D is a disorder of the organization of collagen fibrils into bundles and of the bundles into a strong network ( defective wicker work ) This view has been recently opposed by *Wechsler & Fisher* (1964) who claim that the basic defect is shortness of collagen tissue There is no uniform agreement as to the histological picture Normal increased or decreased amounts of elastic tissue or collagen have all been reported

Autosomal dominance with variable penetrance is the usual form of inheritance although other genotypes may occur

The clinical features are variable The syndrome is commonly noticed in early childhood The patients are usually mentally normal They are often small short and poorly developed The face may be normal or with a broad nasal bridge widely spaced eyes and epicanthus Various ocular changes have been recorded Blue sclerae are seen As a whole the defective collagen and the normal elastic tissue will explain several of the clinical features The skin has a characteristic velvety appearance It can be pulled away in large folds but retracts instantly upon release The elasticity decreases with increasing age and loose folds appear in elderly people The skin is abnormally fragile or brittle Minor trauma or surgery produces gaping fish mouth wounds which are hard to close and heal only slowly Stitches hold poorly in the skin and operation wounds reopen easily Paper thin atrophic scars are other characteristics Minor blows may results in considerable hematomas which may organize to form pseudotumors Pseudotumors also tend to form at pressure points Histologically they show connective tissue proliferation increased vascularity islets of fatty degeneration and cyst formation Subcutaneous nodules on the limbs are frequently seen composed of encapsulated fat with a diameter of 2 8 mm They often calcify which may permit the radiologist to make the diagnosis of E D Acrocyanosis has been a prominent feature of several previous case reports

The hemorrhagic tendency has been ascribed to a vascular defect based upon poor collagen support of blood vessels Recently some cases with abnormal coagulation mechanism have been reported but the majority of cases have shown no abnormality as to coagulation factors (*Day & Zarafonetis* 1961 *Wigzell & Ogston* 1963)

The hyperextensibility of joints is often striking ( India rubber men ) It tends to become less marked as the patient becomes older In addition muscular hypotonicity and underdevelopment seem to exist in these patients The result is a number of musculoskeletal abnormalities *Abnormal positions of extremities and digits are* characteristic There is a marked tendency to habitual dislocation of different joints (hip shoulder patella radius clavicle etc) Joint effusions probably due to repeated trauma are frequent Kyfoscoliosis is likely to develop Flat feet commonly occur Finally the literature comprises more or less sporadic reports on spina bifida occulta arachnodactylia club foot acroosteolysis of finger phalanges radio ulnar synostosis

pigeonbreast high arched palate and dental abnormalities in connection with E-D (*McKusick Johnson & Falls*)

The disturbances in the joints may be noted when the child starts to walk It is particularly obvious if the changes of the knee and ankle joints allow much subluxation In some cases the condition has even been diagnosed as myotonia congenita due to the patient s waddling gait or inability to walk or run fast

Umbilical and inguinal hernias are common and cases of diaphragmatic hernia also occur

In recent years there has been an increased interest in the internal manifestations of the E D They include ectasia of portions of the alimentary tract spontaneous rupture of the lung recurrent hemoptysis dissecting aneurysm of the aorta multiple intracranial aneurysms sinus of Valsalva aneurysm and spontaneous perforation of the bowel with gastrointestinal hemorrhage (*McKusick Robitaille* 1964 *Madison Bradley & Castillo* 1963 *Tucker Miller & Jacoby* 1963 *Rubinstein & Cohen* 1964) E D associated with multiple neurofibromatosis has also been reported (*Turkington & Grode* 1964)

There is no treatment for this disorder Trauma should be avoided Surgical procedures should be undertaken with great care because of the friability and hyperelasticity of skin and internal structures Prognosis for life is usually good although deaths occur from various internal manifestations

## CASE REPORT

The patient a 54 year old woman was admitted to our hospital on suspicion of a malleolar fracture Her gait had been waddling since childhood and her finger joints had always been extremely mobile In younger years she repeatedly suffered from dislocations in both shoulder joints but this had not occurred for the last 12 15 years Even the smallest trauma caused large skin bleedings She did not bleed more than other people on accidental cuts in fingers etc 23 years old she had a cesarian section She was told that she had a contracted pelvis and other skeletal deformities due to serious rachitis in childhood

On *admission* she appeared mentally normal As will be seen from Figure 1 she had a curious frame of body She had a number of subcutaneous hematomas due to the trauma A peculiar gaping wound was seen on her right leg The ankle joints appeared lumpy and deformed The skin could be pulled away in large folds (Figure 2) but rapidly resumed its normal position on release Histological examination of the skin revealed a obvious shortness on collagen fibers and even the elastic fibers were scarce Typical pseudotumors were observed on the anterior aspects of the legs There were also numerous calcified subcutaneous modules in the limbs (Figure 8) The skin was extremely brittle and sutures cut through it

*Figure 1 Figure 2 Hyperelasticity of the skin Figure 3 Acrocyanosis Figure 4 Hypermobility of fingers Figure 5 Hypermobility of fingers*



*Figure 7 Bilateral dislocation of the hip joints*



*Figure 6. Deformity of the spine*



*Figure 8. Lateral radiograph of leg. Subcutaneous calcified nodules. Slight distal displacement of the distal end of the fibula.*

Acrocyanosis was seen on the fingers (Figure 3) There was a marked hype
mobility of the fingers (Figures 4 and 5) and some other joints Finally the
was a walnut sized umbilical hernia and subluxation of several toe joints wi
bilateral hallux valgus

X ray examination revealed a considerable kyfoscoliosis (Figure 6) with torsic
and secondary changes of the vertebrae and discs Furthermore there was
bilateral dislocation of the hip joints (Figure 7) Regarding the changes in tl
legs and ankle joints it was obvious that the leg bones were twisted in relatic
to each other probably due to a subluxation of the fibula. There were son
alterations of the shape of the talus and the heel bone X ray examination of tl
skull hands and clavicle disclosed no obvious changes

Biochemical tests showed normal values for serum calcium phosphorus alkali
and acid phosphatase and proteins The thymol turbidity tests bleeding tim
coagulation time hemoglobin prothrombin time thrombocyt count and whi
blood cell count were all normal Multiple bleedings were observed on the Rumpe
Leede s test

A more thorough study of the hereditary aspects of this case was not possibl
A younger sister who died from sepsis in 1942 showed symptoms analogous t
those of our patient Neither her parents nor her other 6 brothers and sister
her son and granddaughter or other known relatives had symptoms indicating E I

## DISCUSSION

The patient shows several features of the E-D with the typical ski
and joint affections the bleeding tendency the umbilical hernia an
the acrocyanosis Her sister undoubtedly suffered from the sam
disease

It is of course difficult to establish the importance of the connectiv
tissue defect in the development of the hip joint dislocation Congenit
dislocation of the hip has been reported in a case of E D (*Debre & Se
melaigne* 1938) and according to McKusick some cases of habitual hi
joint dislocation have also been reported It is noteworthy that the pa
tient s sister also had symptoms indicating hip joint dislocation Th
patient was deprived of the tendency to shoulder joint dislocations in he
fourth decade of life which is in accordance with the general exper
ence with the E D As mentioned before kyfoscoliosis is a fairly com
mon skeletal manifestation of the E D In some cases a wedge shape
deformity of the vertebral bodies has been demonstrated (*Kornsta*
1953 *MacFarlane* 1959 *Coventry* 1961) The other skeletal manifes
tations of our case are commonly seen in cases of E D

The E-D has for a long time been regarded as a disease of par
ticular interest to the dermatologist However it is also of interest t
the general and orthopedic surgeon It is frequently a typical surgica

condition that makes the patient seek medical help This is evident from the abovementioned Scandinavian papers 2 patients saw a doctor owing to habitual dislocation of the shoulder (*Wigers*) and repeated ankle distortions (*Huseby*) respectively 3 patients reported by *Korn stad* had suffered from shoulder luxation and one patient saw a doctor owing to repeated dislocations of various fingers on one hand *Strand berg s* patient was admitted to a surgical ward with a large femoral hematoma accompanying a minor trauma

SUMMARY

The signs and symptoms of the Ehlers Danlos syndrome are described briefly The surgeon should be aware of this disease owing to the bleed ing tendency and the frequency of dislocation and skeletal deformities The author reports on a 54 year old woman suffering from bilateral hip dislocation marked kyfoscoliosis twisting of the leg bones as well as subdislocations of several toe joints She had also suffered habitual dislocations of the shoulder joints butt this had been cured spontane ously in the fourth decade of her life It is frequently the skeletal or joint manifestations of the Ehlers Danlos syndrome that makes the patient seek medical advice—most commonly a general or an ortho pedic surgeon

RESUME

Les signes et symptomes du syndrome Ehlers Danlos sont succincte ment decrits Le chirurgien doit veiller a cette maladie due a la ten dance aux hémorragies et a la fréquence des dislocations et des defor mites squelettiques L auteur rapportte le cas d une femme agee de 54 ans souffrant d une dislocation bilaterale de la hanche d une cyphoscoliose marquée tordant les os de la jambe ainsi que de sub dislocations de différentes articulations Elle avait souffert aussi des dislocations habituelles des articulations de l epaule mais celles ci s etaient guéries spontanement dans la quarantaine Il arrive fre quemment que ce sont les manifesttations squelottiques ou articulaires du syndrome Ehlers Danlos qui amenent le malade a consulter un medecin—le plus souvent un praticien de médecine generale ou un chirurgien orthopédiste

## ZUSAMMENFASSUNG

Die Kennzeichen des Ehlers Danlos Syndrome wurden kurz beschrieben Der Chirurg sollte auf diese Erkrankung wegen der Blutungsbereitsschaft und der Haufigkeit von Verrenkungen und Skelettdeformiten aufmerksam sein Der Verfasser berichtet uber eine 54 Jahre alte Patientin dia an doppelseitiger Huftgelenksverrenkung ausgesprochener Kyphoskoliose Torsion der Unterschenkelknochen und auch an Subluxation mehrerer Gelenke litt Sie hatte auch an habitueller Luxation der Schultergelenke gelitten doch kam es hier zu einer spontanen Heilung im vierten Jahrzehnt ihres Lebens Häufig sind es die Skelett oder Gelenkserscheinungen des Ehlers Danlos Syndrome die den Patienten zum Arzt fuhren —meist zum allgemeinen oder orthopadischen Chirurgen

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# THE HEXATRON

## *A new Thumbgoniometer*

*By*

B Ebskov and C Boe

Received 29 VII 65

Interest in the study of the kinesiology of the human thumb dates back many centuries *Galen* (a 200 A D ), *Winslow* (1752) *Bichat* (1802) *Duchenne* (1867) *du Bois Raymond* (1895) and *Fick* (1911) have all contributed to information on this topic through their studies Whereas these authors have developed the anatomic and physiologic aspects the more recent authors mainly represent clinicians—orthopaedists and hand surgeons (*Grunkorn* 1932 *Bunnell* 1938 1956 *Goldner & Irvin* 1950 *Wheeler Haynes* 1944 *Kaplan* 1953 and *Littler & Cooley* 1960 1963)

The various theories proposed throughout the years have been generally based on 1) anatomical studies 2) electrostimulation studies (*Duchenne* 1867) and recently electromyographic techniques (*Weathersby et al* 1963) The anatomical studies have been supplemented by observing the angular displacements following controlled tension on the isolated tendons The registration of movements has been mainly by the visual observation of the naked thumb In some cases this registration was facilitated by indicators placed on the thumb eventually working against a system of scales (*Bunnell* 1956 *du Bois Raymond* 1895) *Roentgenologic registration has also been utilized* (*Mannerfelt* 1964) Simple visual observation is probably the least unsatisfactory of the methods previously used unless the purpose is to record movements in one plane in which case x ray photography or cineflourography works well Those systems which depend on indicators placed on the thumb are subject to potential sources of error *due to the motion of the skin in relation to the underlying bone* There has not been described any exact method of registering the thumb movements throughout the full normal range

One of the authors (B E) studied thumb kinesiology for some years Originally a study was planned using electromyography registration of the movements such as *Long et al* (1960 1961 1962) have used on the fingers Whereas cinematography is satisfactory (in respect of reliability) when aimed at movements in one plane only (*e g* the hinge movements of the interphalangeal joints of the finger) this method has not proved reliable when applied to the more complex circumductory range of the thumb Specifically it has been impossible to determine the degree of rotation that occurs coincidentally with opposition The use of two synchronized movie cameras or one camera connected with a system of mirrors has been suggested but such methods are difficult and the results singularly complicated Furthermore we feel convinced that such readings will involve considerable errors With these considerations in mind it was tempting to apply a more advanced technology to the problem Working a number of theoretical considerations and discussions one of the authors (C B) designed the apparatus to be described in the following

Prior to the physical shaping of the goniometer the authors agreed on the following ideal requirements The goniometer should

1 permit complete and unrestricted movement of the finger examined (This means that the apparatus has sufficient range in all directions has no static or dynamic loading and does not exercise resistance against the movement of the thumb)

2 be simply though safely attachable to the finger examined and

3 yield good and reproducible readings

The authors feel that the usual demand for simplicity of construction and immediate correlation of results is somewhat antiquated and—if rigidly upheld— denies the potential application of advanced technological systems

The apparatus is principally based on a three-dimensional linkage mechanism (shown in Figure 1) consisting in two congruent ternary links ABC and DEF and three binary links of equal length CF BE and AD All joints are thought to be ball joints In case only two of the binary links are parallel the agular orientation of the ternary links ABC and DEF This necessary condition can be achieved by letting two of the ball joints (*e g* C and F) be replaced by two universal joints with parallel yokes

By doubling the system as shown in the dotted lines in Figure 1 it is possible to have two elements ABC and CHK which are rotationally coupled but within certain limits translationally unrestricted

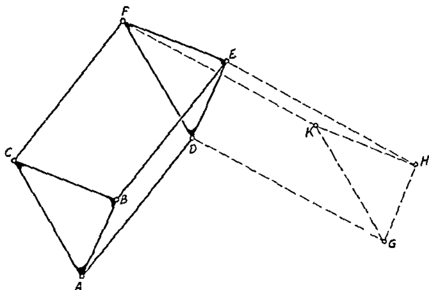



*Figure 1 Simple linkage mechanism for transferring of rotation*

With few alterations the system can be recognized in Figure 2 Here (c) will make the same angular movements as (b) which again will have to follow link (a) in its rotations Thus link (c) will follow link (a) which is attached to the thumb Link (d) and (f) are hinged so that they will always be in a vertical plane The angular position of this vertical plane according to the reference system (as measured with transducer 6) in connection with the horizontal angles of link (d) and (f) (from transducer 4 and 5) gives the translational position of the point (p) The angular movements of link (e) according to link (g) (the position of which is determined by transducer 4 5 and 6) are measured by transducer 1 2 and 3 Thus the signals from the six transducers will contain complete information about the movement of link (a) and hence about the thumb

High precision gold wire potentiometers are used for transducers with very little frictional torque They are placed in such a way that they tend to balance the whole system and by further addition of three balance weights the system can be brought in complete balance so that even the weight of the splint attaching the thumb with link (a) can be compensated The dynamic loading is kept small by the application of very light materials and small dimensions Either small single groove ball bearings or saphirs are used for pivots

The signals are digitized and fed into a digital computer which

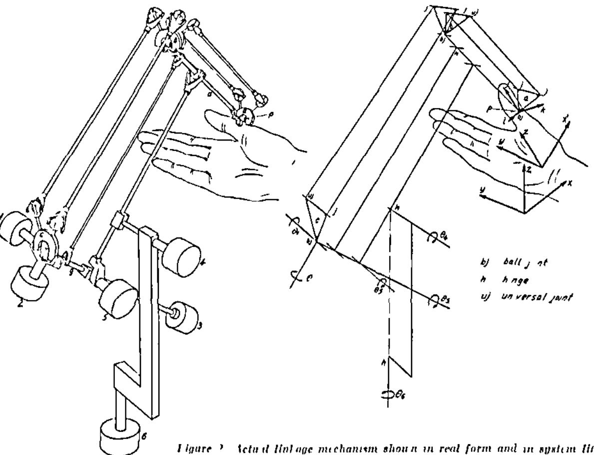



Figure 2 Actual linkage mechanism shown in real form and in system lines

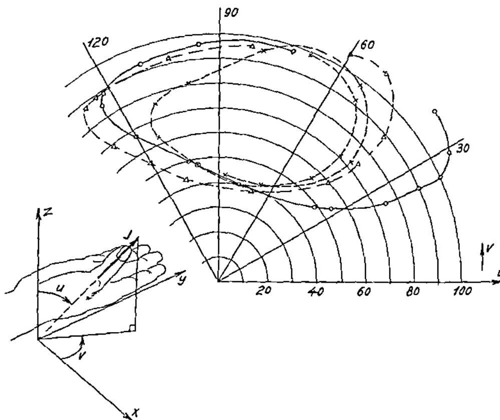



*Figure 3 Maximum mobility of phalanx for three different persons Shown in polar plot*

determines the position of the unity vectors i j and k (connected to the fingersplint) according to the computational reference system x y z and afterwards transforms the results to the hand reference system x y z Of course the results can be presented in any desirable form

In Figure 3 the maximum mobility of proximalis is shown for three persons For the measurements a splint is used which allows free movement in both the carpometacarpal joint and in the metacarpo phalangeal joint

Assuming the existense of relatively fixed points between meta carpale and carpus and between metacarpale and proximalis during the movement it is possible further to compute the positions of the metacarpale as shown in Figure 4 The validity of the assumption concerning the relatively fixed point between metacarpale and carpus

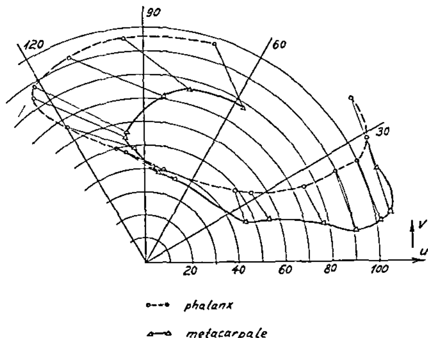



*Figure 5. Measured positions of phalanx and metacarpale shown in polar plot. Points belonging together are connected.*

(i.e. metacarpale having spherical motion) may be proved by applying a splint which blocks the metacarpophalangeal joint. Roentgenologic examinations have shown that it is possible to construct such a splint which with good accuracy follows the metacarpale without restricting the movement of the carpometacarpal joint.

Eventually the possibility exists of further equipping the "hexatron" with a transducer to give the movement of the interphalangeal joint. It will then be possible completely to map out the movements of the thumb bones from the "hexatron" signals.

Mechanical test procedures have shown an angular accuracy of 1°, while the position of a selected point of the splint can be determined within ± 1.5 mm. This includes errors due to incorrect dimensions of the apparatus, unlinearity of the transducers and errors from the digitizing. For a normal person the "hexatron" will not restrict the movement of the thumb. Static loading of the finger is eliminated, but at rapid movements there will be some inertia loading.

At present one of the authors (B. E.) is applying the "hexatron" at Highland View Hospital, Cleveland, for kinesiologic studies. Moreover

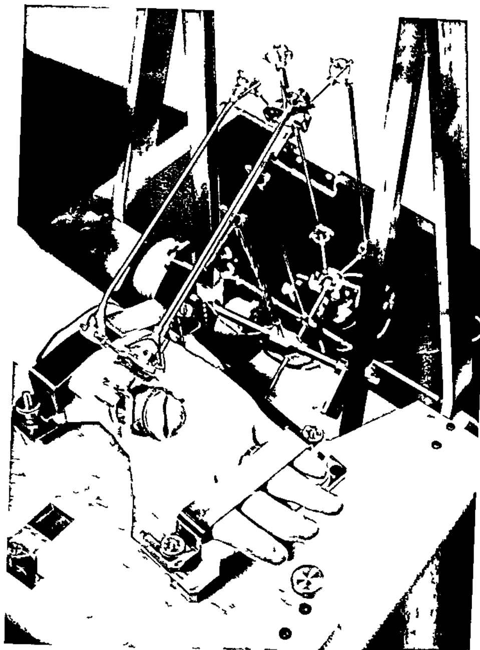


*Figure 5 The HEXATRON in function*

it may be useful in the clinical examination of thumb injuries and in follow ups after operations


SUMMARY

The article deals with the possible methods of measuring thumb movements and describes a new goniometer which through a mechanical linkage system transfers the thumb movements to a number of transducers the signals of which are transformed in a digital computer to give the wanted information

The "hexatron will allow free movement within normal range without static loading of the thumb Angular accuracy of 1 and translational accuracy of 1 5 mm have been achieved

RESUME

L article traite des methodes qui permettent de mesurer les mouvements du pouce et decrit un nouveau goniometre qui au moyen d un système d enchainement mécanique transfere les mouvements du pouce a un certain nombre de transmetteurs dont les signaux sont transformes par un computer digital pour donner le renseignement souhaite

L«hexatrone» permet les libres mouvements dans une etendue normal sans effort statique du pouce On a obtenu une precision angulaire de 1 et une precision translationnale de 1 5 mm

ZUSAMMENFASSUNG

Die Arbeit befasst sich mit den moglichen Methoden zur Messung der Daumenbewegungen und beschreibt ein neues Goniometer das mittels eines mechanischen Raumgetriebe die Daumenbewegungen auf eine Anzahl von Messwertgeber überfuhrt deren Signale in einem digitalen Rechenmaschine umgeformt werden um den gewunschten Aufschluss zu geben Das Hexatron gestattet freie Bewegungen innerhalb des Normalbereiches ohne statische Belastung des Daumens Winkelgenauigkeit von 1 und translatorische Überführungsgenauigkeit von 1 5 mm wurden erzielt


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From the Nuffield Orthopaedic Centre Oxford

# THE ACRYLIC SCAPHOID PROSTHESIS IN THE TREATMENT OF THE UNUNITED CARPAL SCAPHOID FRACTURE

By

J C Agerholm[1] and M L H Lee

Received 24 I 65

The numerous recommended methods of treatment of ununited fractures of the carpal scaphoid bone underline the problem of management of this condition and have been summarized by *Agner* (1963)

Having had promising results in the excision of the necrotic carpal lunate and its replacement with an acrylic prosthesis (*Agerholm & Goodfellow* 1963) it was natural to consider a similar procedure for ununited fractures of the carpal scaphoid There are two difficulties one has to remember

First of all the shape of the scaphoid is far more complicated than that of the lunate It is therefore far more difficult to find a suitable fitting prosthesis

Secondly the position of the scaphoid in the carpal row is not as stable as that of the lunate The latter is very well supported by the neighbouring bones and even during operation the lunate prosthesis is quite stable in the open wound Furthermore after lesions such as fractures and sprains it is likely that the capsule and ligaments of the scaphoid which normally keep the bone in its proper place have suffered However one of us (J C A ) decided to try this procedure in patients with old ununited fractures of the scaphoid and marked osteoarthritic changes giving so much trouble that the patients were prepared to accept arthrodesis of the wrist and in more recent fractures with avascular necrosis of the proximal fragment

The purpose of this paper is to give an independent assessment (M L H L ) of this method of treatment

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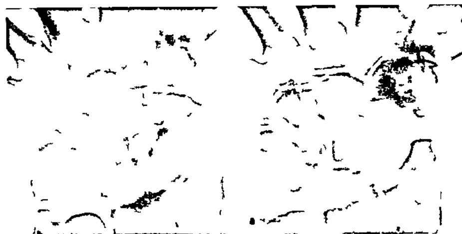


*Figure 1 Patient No 7 pre-operatively and over 5 years following replacement of the scaphoid by an acrylic prosthesis Note the post operative subluxation of the capitate on the lunate and the residual bony fragments*

records there was no significant change in movement except for Patient No 7 who suffered a marked loss of movement perhaps due to the degree of carpal collapse (Fig 1) following operation though this does not seem to have affected the range of movement in Patients No 1 and 14 who also suffered some post-operative carpal collapse

It is striking how in several patients a remarkably good range of abduction and adduction was retained despite moderately severe restriction of flexion and extension

There was no association between the range of movement and the presence of pain

*Power*

By the use of a pinch gauge the pinch between the thumb and finger and that between the thumb and isolated index finger can be estimated with reasonable accuracy and compared with the power in the normal hand

This comparison could not be made in four wrists as one patient (Nos 5 and 11) had had the operation bilaterally and two (Nos 1 and 13—Fig 2) had disabling conditions of the opposite wrist Because of this the grip of the affected hand has been estimated as a percentage of the average grip of the normal hands of the patients under review (Table 1)

TA

| Patient | Sex | Occupation | Age at operation | Years of symptoms operation before | Follow up (years and months) | Son pai |
|---|---|---|---|---|---|---|
| 1 | ♂ | Engineer | 27 | 20+ | 8–1 | Y |
| 2 | ♀ | Housewife | 64 | ½ | 6–1 | Y |
| 3 | ♂ | Labourer | 55 | 20+ | 5–9 | N |
| 4 | ♂ | Medical Practioner | 37 | 1 | 5–5 | Y |
| 5 | ♂ | Joiner | 43 | 10 | 5–3 | Y |
| 6 | ♂ | Painter | 54 | 20+ | 5–3 | N |
| 7 | ♂ | Bricklayer | 59 | 20+ | 5–1 | N |
| 8 | ♂ | Labourer | 44 | 20+ | 4–10 | Y |
| 9 | ♂ | Chairmaker | 49 | 3 | 3–10 | Y |
| 10 | ♂ | Engineer | 28 | 8 | 3–8 | Y |
| 11 | ♂ | Joiner | 45 | 10 | 3–4 | Ye |
| 12 | ♀ | Housewife | 34 | 20+ | 3–4 | Ye |
| 13 | ♂ | Brewery hand | 26 | 5 | 1–6 | Ye |
| 14 | ♂ | Publican | 51 | 20+ | 1–6 | No |

Only the wrists of patients No 2 8 11 and 12 were below 80 per cent of the average normal power though the thumb/finger grip of patient No 4 was reduced Patients 2 (Fig 3) and 12 were both women and may reasonably be expected to have a grip below the average power in fact the grip of patient 2 was about equal to that of her normal hand though in patient 12 it was significantly reduced without obvious cause other than marked osteoarthritic changes Patients 8 and 11 also had marked degenerative changes however patients 5 and 6 had marked degenerative changes without severe loss of grip

### *Durability*

Deterioration with time was not apparent No patient recalled any change of symptoms after the first year following operation It is interesting that the first four patients in Table 1 have the best range of movement despite the length of time since insertion of the prosthesis patients 2 (Fig 3) and 4 showing no osteoarthritic changes 6 and 5½ years following operation

| on review ...xion | Extension | Abd/Add as fraction of normal | Pre and post operative degree of osteo arthritis | Carpal Collapse Pre op | Carpal Collapse Follow up | Power as % of average normal power Pinch | Power as % of average normal power Thumb Index |
|---|---|---|---|---|---|---|---|
| 60 | 40 | ½ | + | No | Yes | 112 | 160 |
| 60 | 60 | 1 | No | No | No | 76 | 75 |
| 70 | 40 | ⅓ | + | No | No | 107 | 94 |
| 65 | 65 | ¾ | No | No | No | 87 | 66 |
| 25 | 50 | ¾ | ++ | No | No | 82 | 85 |
| — | 10–30 | ¼ | ++ | Yes | Yes | 97 | 113 |
| 30 | 30 | ¾ | + | No | Yes | 112 | 105 |
| 30 | 30 | ¾ | ++ | No | No | 56 | 60 |
| 45 | 60 | ⅘ | + | No | No | 92 | 71 |
| 25 | 25 | ½ | + | No | No | 82 | 94 |
| 45 | 25 | ¾ | ++ | Yes | Yes | 66 | 75 |
| 30 | 30 | ¾ | ++ | No | No | 61 | 38 |
| 45 | 50 | ⅔ | No | No | No | 87 | 104 |
| 70 | 45 | 1 | + | No | Yes | 112 | 85 |

## RADIOLOGICAL APPEARANCES

### *Osteoarthritis*

This was assessed by the degree of spiking of the styloid process of the radius and by the presence of osteophytes on the dorsal and palmar margins of the radius as seen on lateral radiographs

It was considered to be marked in 5 wrists (Fig 4) absent in 3 wrists (Figs 2 and 3) and only slight in 6 wrists In no patient did it appear to have altered in degree as a result of the operation

TABLE 2

| Severity of osteoarthritis | Average flexion plus extension movements |
|---|---|
| Marked | 57 |
| Slight | 90 |
| Absent | 115 |

A direct relation between the degree of osteoarthritis and the range of flexion and extension was found as is shown in Table 2 It did not

## CONCLUSIONS

In our experience replacement of the ununited fracture of the scaphoid by an acrylic prosthesis gave satisfactory results in 14 of 16 wrists with retention of the pre operative range of movement a satisfactory grip maintenance of the *normal carpal relationship and without* progression of osteoarthritis

This is in direct contrast to the experience of *Agner* who reviewed 7 cases in whom the scaphoid was replaced by an acrylic mould of the cavity in a two stage procedure 5 of his cases had to have the prosthesis removed and the wristt arthrodesed 6 months to 3 years later because of increasing pain and stiffness Although the period of review is less than the 9 to 11 years of *Agner* s cases 12 of our patients have been followed up for more than 3 years and there is no indication that any progressive deterioration is taking place It is not easy to account for these different results but it is possible that a cause of the marked periarticular fibrosis found by *Agner* is due to the double operative procedure rather than to the acrylic material itself which can suffer minimal wearing forces in this non weightbearing joint In addition a preformed prosthesis of normal anatomical configuration is more likely to retain normal carpal relationships and therefore better functional results

Our findings indicate that acrylic replacement of the carpal scaphoid is a useful procedure and may well be recommended if retention of mobility is desired and arthrodesis avoided It is worth a trial even if osteoarthritis is established and it may also be considered suitable in the early treatment of scaphoid fractures of the elderly as the period of immobilisation is short

## SUMMARY

An anatomically modelled acrylic prosthesis was used to replace an ununited fracture of the scaphoid in 16 wrists injured between 3 months and 20 years previously Two wrists required arthrodesis—one after 4 months through dislocation of the prosthesis and one after 5 years because of pain and stiffness of the wrist and fracture of the prosthesis 14 wrists were reviewed between 1½ and 8 years after operation (7 were seen over 5 years after operation) 4 wrists were painless and the other 10 suffered only minor pain after heavy stress The 14 patients retained their pre operative movements had a good grip and osteoarthritis did not progress 11 wrists maintained their carpal relation

ships The procedure is considered valuable in late cases of non union and in more recent injuries of the elderly

## RESUME

Une prothese acrylique modelee anatomiquement a ete utilisee pour remplacer une fracture non soudee du scaphoide dans 16 lesions du poignet intervenues entre 3 mois eet 20 ans auparavant Deux poignets ont demande l arthrodese – l un apres 4 mois par suite de la dislocation de la prothèse et l autre apres 5 ans par suite de douleurs de rigidite du poignet et de fracture de la prothese 14 poignets ont été soumis a un nouvel examen entre 1½ et 8 ans apres l operation (7 avaient ete opérés depuis plus de 5 ans) 4 poignets ne presentaient pas de douleurs et les autres souffraient seulement de douleurs legeres apres un grand effort Les 14 malades ont regagne leurs mouvements pre operatoires avec une bonne faculte de saisir et l osteoarthrite ne fit pas de progres 11 poignets ont maintenu leurs contacts carpiens La procedure est consideree avoir de la valeur dans les cas tardifs de non soudure et dans les lesions plus recentes chez les personnes agees

## ZUSAMMENFASSUNG

Eine anatomisch modellierte Akrylprothese wurde verwendet um nichtgeheilte Navikularebruche bei 16 Handgelenken die zwischen 3 Monaten und 20 Jahren vorher geschadigt worden waren zu ersetzen Zwei Handgelenke erforderten Arthrodese – eines nach 4 Monaten wegen Luxation der Prothese und ein anderes nach 5 Jahren wegen Schmerzen und Steifheit des Handgelenkes und Bruch der Prothese 14 Handgelenke wurden von 1½ bis 8 Jahren nach der Operation nach untersucht (7 waren 5 Jahre nach der Operation) 4 Handgelenke waren schmerzlos und die anderen 10 hatten nu geringe Schmerzen nach starker Anstrengung Die 14 Patienten behielten ihre voroperative Beweglichkeit hatten einen guten Griff und die Osteoarthritis schritt nicht fort 11 Handgelenke behielten ihre carpale normale Lage bei Das Vorgehen wird in späten Fallen von Nichtheilung und bei neueren Verletzungen von alteren Patienten als wertvoll angesehen

## ACKNOWLEDGEMENTS

The acrylic prosthesis were made by Mr *Alan J Anderson* Senior Dental Technician (Surgical) in Charge Oral and Maxillo facial department The Churchill Hospital Oxford whose assistance is gratefully acknowledged

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In our experience replacement of the ununited fracture of the scaphoid by an acrylic prosthesis gave satisfactory results in 14 of 16 wrists with retention of the pre operative range of movement a satisfactory grip maintenance of the normal carpal relationship and without progression of osteoarthritis

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# HIP ARTHRODESIS

## *The Connection between Function and Position*

*By*

SVEN OLOF AHLBACK[1] AND OLOV LINDAHL

Received 2? IV 65

While the indications and the technique for the hip arthrodesis operation have been thoroughly treated in the literature the problem of the best position for the hip is usually dismissed in a few lines often a particular position is recommended as giving "the best results but the grounds for the choice are rarely specified nor does the relationship between position and function seem to have been analysed in a followed up case material

The following recommendations have been made in respect of the transverse frontal and sagittal planes

*Position in the transverse plane*—The preferred angle of rotation ranges from the mean to an outward rotation of 15 (2 3 6 7 9 10 14 17) Inward rotation is considered to be incorrect *Watson Jones* (16 17) specifies the mean position stating that any other recommendation is of course nonsense As a rule no information is given on how the angle was measured

*Position in the frontal plane*—Abduction between 0 and 25 have been mentioned (2 3 6 7 8 14 17) 25 being regarded as acceptable for children while for adults 20 is the maximum It is commonly held that any real shortening shall be compensated for by abducting the leg and tables giving the appropriate abduction for different degrees of shortening have been compiled (1 9 10) Some authors caution against excessive abduction recommending up to 10 others prefer the zero position on the grounds that static scoliosis is liable to lead to back troubles No objective examination of the possible connection between

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Orthopaedic surgeon

abduction and back pains seems to have been published Here too the mensuration technique is usually not touched upon Mention is occasionally made of the possibility of evaluating abduction on radiographs by measuring the angle between the axis of the femur and a horizontal line through the pelvis Usually the mensuration is done by the regular clinical technique i e by measuring the angle between the two spinae and the axis of the thigh

*Gardiner* (8) alone prefers slight adduction which has been found to give a better gait than any other position

*Position in the sagittal plane*—Various flexion angles between 20 and 35 have been deemed the most suitable (1–10 13–17) a larger angle generally being preferred for patients with sedentary in contrast to standing occupations 5–10 between these two alternatives in usually considered to be suitable No methods has been given for the examination of a mobile or an anchylotic hip nor for obtaining the desired position on an operation or plaster table

*Watson Jones* (16 17) states that the recommended flexion of 30 is obtained by placing the patient on a plane with the thoracic spine seat and neck at the same level when the natural lordosis of the lumbar spine will give the required angle In an earlier study *Ahlbäck & Lindahl* (4) have shown however that the flexion of the hip in this position ranges from 7 to 22 —based on a zero position in maximum extension In the commonly used nomenclature flexion is defined as zero in the supine position

The disparity between the recommendations of the various authors together with the absence of rigorous standard methods for measuring the position of an arthrodesed hip joint prompted the following study of hip arthrodesis cases with special reference to the relationship between the position of the hip joint and function as reflected in the gait and comfort in the seated position The function in daily life after hip arthrodesis has been dealt with in a separate study (12)

## MATERIAL

The follow up clinical examination was performed on 35 patients who had been provided with a hip arthrodesis at least 2 years previously The age and sex distributions were as follows

| Age | < 40 | 40–49 | 50–59 | 60–69 | > 69 | Total |
|---|---|---|---|---|---|---|
| Men | 4 | 5 | 5 | 10 | 4 | 28 |
| Women | 1 | 1 | 1 | 2 | 2 | 7 |
| Total | 5 | 6 | 6 | 12 | 6 | 35 |

## METHODS

A careful case history was taken for each patient In the subsequent examination special attention was devoted to the gait comfort when seated and the position in which the hip joint had been fixed

*Gait* — The gait was judged mainly from the aesthetic standpoint Note was made of limping (asymmetric gait) circumduction wide gait dropping on one leg and placing only the stiff leg in front of the other On the basis of this evaluation the gait was classed as good fair or poor good implies practically normal walking the leg being placed alternately one in front of the other poor gait was recorded when there was pronounced limping or asymmetry circumduction or markedly wide gait

*Sitting* —On the basis of the patient s ability to sit comfortabl and in a normal position on ordinary chairs toilet stools and cinema seats the sitting function was classified as good fair or poor

*Position in the transverse plane* —The patient was placed supine with the knees extended and the ankles in dorsal extension The angle between the vertical plane and the median contour of the foot (heel to head of the first metatarsal bone) was measured with an instrument designed for the purpose

*Position in the frontal plane* —A method devised by *Lindahl* (11) for determining the position of the hip in the frontal plane was applied The adduction (or abduction) was taken as the difference between the real shortening of the leg measured on radiographs and the distance between the medial malleoli measured in the axial direction of the leg with the feet together

*Position in the sagittal plane* —In an earlier study (4) of the range of sagittal movement in the hip joint it was found that an accurate determination of the flexion of the joint demanded a more reliable reference position than is generally used Accordingly in the present study the position in the sagittal plane was measured from full extension Provided that the other hip is normal the flexion position of an arthrodesed hip will correspond to the difference in the angle between the thighs when the mobile hip is fully extended For the measurement the patient is placed supine with both legs outside the examination couch and dropped to the full extent so that there is pronounced lordosis The difference in the angle between the thighs is measured with a special instrument having long arms (4) If comparison cannot be made with a normal hip joint the angle of flexion cannot be assessed clinically but it can be measured approximately on a lateral radio graph as the angle between the conjugata vera (a line between the promontory of the sacrum and the symphysis) and the axis of the femur In the authors series of 36 patients with clinically and radiographically normal hips chiefly men ranging in age from 4? to 67 years the mean of this angle in full extension of the hip joint was 50

For 8 cases of osteo arthritis the mean was 33 In cases in which the mobile hip was al o diseased the flexion in the rigid hip was measured on radiographs as the difference between 50 and the actual angle between the axis of the femur and the conjugata vera

*Radiographic examination* —A frontal film was taken of both hip j Ints the pelvis and the upper part of both femurs with the central ray passing midway between the hip joints Lateral films were taken of the same region with the m bile

hip fully extended and flexed the central ray passing through the hip joints The film – focus distance in both cases was 100 cm

## RESULTS

*Position in the transverse plane*—The rotational position of the hip-joints provided with arthrodeses were as follows (— denotes inward and + outward rotation)

| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| —4 | 0 | +5 | 8 | 10 | 10 | 13 | 13 | 15 | 15 | 18 | 20 | 20 | 20 | 22 | 22 | 24 |
| 25 | 25 | 27 | 27 | 28 | 30 | 30 | 30 | 35 | 35 | 35 | 40 | 40 | 45 | 55 | 62 | 75 |

Angles from an inward rotation of 4 to an outward rotation of 75° are represented All but 4 of the patients were content with the position of the foot so far as the angle of rotation was concerned Two complained on cosmetic grounds (—4 and +40 ) one (+62 ) had difficulty in placing the foot on the accelerator and one (+75°) was unable to sleep on the side of the fixed hip because owing to a stiff knee the foot pointed down into the mattress There was neither subjective nor objective evidence that the gait or seated position was affected adversely by the rotary position of the foot

*Abduction and adduction*—Only 4 out of 35 patients (11 per cent) complained of back pains that they ascribed to the arthrodesis The distribution of these cases in the group was such that it was impossible to establish whether there was any link between the symptoms and pronounced malposition the adduction was —33 —28 —2 and +4 mm (*+ denoting abduction in relation to the neutral position (11)*)

*Table 1 Connection between the gait and the functional length of the leg Negative values denote a shortening and positive ones a lengthening on the arthrodesis side*

| | Difference in length (mm) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Good | —10 | — 5 | — 5 | — 5 | — 5 | 0 | 0 | 0 | 0 | + 5 |
| Fair | —30 | —25 | —20 | —20 | —15 | —15 | —5 | —5 | 0 | + 5 |
| Poor | —70 | —45 | —40 | —40 | —40 | —30 | —5 | 0 | 0 | +10 |
| | +10 | +20 | +20 | +30 | +45 | | | | | |

It is evident from Table 1 that on an average the gait was better for equal functional length of leg than for large differences in either direction In the patients with approximately equal length of leg but poor gait the latter was generally ascribed to other factors such as bad flexion position stiff back or painful osteoarthritis in the mobile hip In the

above evaluation of gait the patients were required to walk without shoes By raising the shoe—the height being changed from time to time—the gait could be improved However many did not care to compensate for the shortening in this way preferring to walk with the mobile leg slightly flexed at the knee and hip

A corresponding compilation of gait and position in the frontal plane (abduction and adduction) shows largely the same results since the functional length of the leg and the position in the frontal are of course interdependent

*Flexion angle*—As would be expected the seated position was more comfortable the greater the angle of flexion in which the hip was fixed (Table 2) The exceptions to this rule had particularly marked or restricted mobility of the lumbar spine the seated position being respectively more or less comfortable

*Table 2 Connection between comfort in seated position and flexion angle for the arthrodesed hip measured from full extension Negative values denote that the fixed hip was extended more than the sound one in full extension*

| Comfort in seated position | Flexion angle | | | | | | | | | | | | | | | Mean |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Good | 30 | 35 | 35 | 40 | 40 | 45 | 50 | 50 | 55 | 60 | | | | | | 44 |
| Fair | 20 | 20 | 20 | 25 | 28 | 30 | 30 | 35 | 38 | 40 | | | | | | 29 |
| Poor | —5 | 0 | +15 | 18 | 18 | 19 | 20 | 20 | 22 | 23 | 30 | 30 | 34 | 35 | 40 | 22 |

*Table 3 Connection between gait and flexion angle for the fixed hip measured from full extension Negative values denote that the fixed hip was extended further than the sound one in full extension*

| Gait | Flexion angle | | | | | | | | | | | | | | | Mean |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Good | 25 | 30 | 35 | 35 | 40 | 40 | 40 | 45 | 50 | 60 | | | | | | 40 |
| Fair | 18 | 20 | 20 | 28 | 30 | 30 | 35 | 37 | 50 | 55 | | | | | | 32 |
| Poor | —5 | 0 | +15 | 18 | 19 | 20 | 20 | 20 | 22 | 23 | 30 | 30 | 34 | 35 | 40 | 21 |

On an average the gait too was better the greater the flexion angle (Table 3) There was in this respect no appreciable difference between the gait and the comfort in the seated position

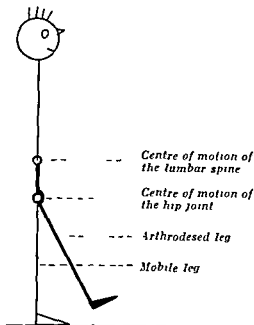



*Figure 1 A*

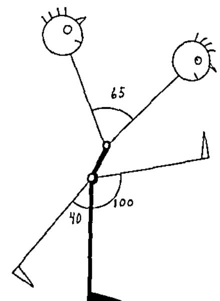



*Figure 1 B*
*The normal ranges of movement in the lumbar spine and the mobile hip joint when standing on the arthrodesed leg with the hip joint fixed in the theoretically ideal angle of flexion*

## MECHANICS OF WALKING AND SITTING WITH AN ARTHRODESED HIP

This discussion is based on movements of the lumbar spine and the mobile hip-joint measured and evaluated in relation to the axial direction of the thigh on the side of the arthrodesis (Figures 1 A and B)

For a fairly long pace forward the angle between the legs is normally about 50 For the person with an arthrodesis an angle of 40 may be assumed to be large enough When the mobile leg is put forward it would then be necessary for the mobile hip to be flexed 40 in relation to the fixed one (Figure 1 C) At the same time the lumbar spine is extended in relation to the pelvis (which is fixed to the femur on the arthrodesed side) this extension will be only one half as great or 20 When the next pace is taken from this position and the stiff leg is placed in front of the mobile position and then extended a further 40 —provided that the flexion angle in which the hip-joint has been fixed is large enough and a full pace is taken (Figure 1 D) During the first

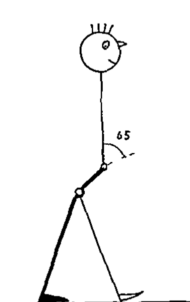



*Figure 1 C*

*Positions of the back and legs when a 40 pace is taken with the mobile leg For the thorax to remain upright full extension of the lumbar spine (lordosis) is required Such a pace can be taken even if the arthrodesed hip joint is fixed in slight flexion or extension It is often the only one the arthrodesis patient can take*

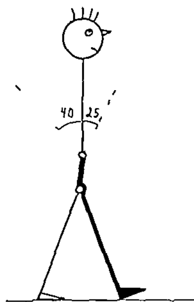



*Figure 1 D*

*Positions of the back and legs when a 40 pace is taken with the arthrodesed leg The lumbar spine is then slightly flexed This step cannot be taken unless the angle of flexion in which the hip is flexed is at least 40*

half of the step the lumbar spine will be flexed 20 and then as the stiff leg is brought up it will be bent a further 20 A total movement of 80 will then have been made in the mobile hip joint and 40 in the lumbar spine For such paces the following conditions are thus necessary the flexion angle for the fixed joint shall be 40 (measured from a zero posotion in full extension) the mobile hip shall have a flexibility of at least 80 the range of movement of the lumbar spine shall be 40 and the direction of movement shall be such that the angles on each side of the axis of the fixed thigh are the same The gait of the few patients meeting these requirements was nearly perfect If the flexion angle were less than 40 it would not be possible to place the rigid leg so far forward and in the case of a very small flexion angle the stiff leg could

not be placed in front of the mobile one, then only the mobile leg could be moved in advance, the rigid one being only brought up to it.

In the seated position the flexion must be performed entirely in the lumbar spine if the patient is not to sit obliquely or with the stiff leg to the side of the chair. For sitting on an ordinary hard chair with the back against the rest the lumbar spine must be flexed 90° in relation to the stiff thigh. Few people sit so upright as this, as it is usual for one to slip forwards on the chair to such an extent that a flexion of the lumbar spine of only 40–50° is required. A person with a hip-joint fixed at a flexion of 45° will not be uncomfortable in any chair. To be able both to sit and to walk well a 20° extension and a 45° flexion in the lumbar spine are thus required. But the normal range of movement of the lumbar spine is about 65°, so that the above values should suffice to enable the person with a hip arthrodesis to both sit and walk without discomfort.

The soundness of this theoretical argument was borne out by the observations. Except for the cases in which the gait was affected by other factors, the patients who could walk best were those with the hip joint fixed at a flexion angle of 40–50° and with normal mobility of the lumbar spine.

## DISCUSSION

From the results of this study the gait and comfort in the seated position would appear not to be appreciably dependent on the *rotational position*. It would, however, seem to be an advantage chiefly for cosmetic reasons to avoid inward rotation and extreme outward rotation. In normal walking and standing the feet are usually rotated 10–20° outward and fixation in this position is therefore to be recommended for an arthrodesis operation. A greater outward rotation may be a disadvantage from a theoretical standpoint, although no patient with such a position complained of it. In the case of outward rotation the knee will not articulate in the sagittal plane, a disadvantage in for example cycling. In the seated position an outward rotation will cause the lower leg to point inwards when the knee is flexed. In walking the movement of the foot will also be abnormal.

As regards the position in the *frontal plane*, the present method devised for measuring an adduction position provides considerably greater accuracy.

An important question is whether to compensate for a real shortening by abduction. Any such compensation (measured from the "neu

tral position [11]) results in a static scoliosis when the fixed hip is loaded There was no evidence of a connection between back symptoms and static scoliosis in the present series but the chance of such symptoms would probably increase with time and there is little reason to run this risk when a shortening of 1–2 cm can readily be compensated for by flexing the mobile hip and knee or by raising the heel on the rigid side

As regards the position of the hip in the *sagittal plane* not only the seated position but also the gait were better when the flexion angle was larger than is usually recommended The values recorded are in conformity with the results of the above mechanical analysis of the gait in the case of a fixed hip Provided that the range of movement of the back is normal a flexion angle of about 45° is to be recommended on the basis of this study One reason that this value is greater than is usually recommended is that the measurement was made from full extension while the ordinary reference position though not defined usually implies a flexion of between 7 and 22° from full extension If this angle is subtracted it is found that the recommended 45° is not much greater than that usually proposed

At ages when a hip arthrodesis is most commonly performed there is usually a restriction of the flexibility of the lumbar spine In these cases a 45° angle of flexion in the hip-joint cannot be used

A patient with an arthrodesed hip is usually very satisfied with the operation (freedom from severe aching and troublesome pains when walking) quite apart from the comfort in the seated position and his ability to walk normally One reason for this is no doubt that the patient has no other possibly better position with which to compare Since the hip arthrodesis is a permanent thing and the patient must live with it to the end of his days it is encumbent on the surgeon to make every effect to ensure the most suitable position and to fix the hip accurately in this position even though this may entail considerable practical difficulties

## SUMMARY

The position for a hip arthrodesis recommended in the literature varies widely from one author to another Methods for measuring the position of a stiff hip are rarely reported and those that are are wanting in accuracy

In 35 patients provided with a hip arthrodesis the relationship between the position of the hip and the gait and comfort in the seated

position has been examined The mensuration techniques for determining the position for the rigid hip are described The results show that the rotational position is apparently of minor importance so far as function is concerned and that the best gait is obtained with a setting in the frontal plane near the neutral position (11) with little shortening In the sagittal plane the gait and comfort in sitting were best when the flexion angle of the hip was 45 (measured from a zero position in full extension)

The results were in close conformity with the theoretical values obtained from an analysis of the mechanics of the mobility of the lumbar spine and the sound hip after arthrodesis

## RESUME

La position recommandee dans la litterature pour l arthrodèse de la hanche varie beaucoup d un auteur a l autre Les methodes pour mesurer la position de la hanche rigide sont rarement rapportees et celles qui le sont manquent de precision

Chez 35 malades ayant une arthrodese de la hanche on a examine le rapport entre la position de la hanche et la marche ainsi que le confort dans la position endommagee Les techniques de mensuration pour determiner la position de la hanche rigide sont décrites Les resultats montrent que la position de rotation est apparemment d importance mineure en ce qui concerne la fonction et que la meilleure marche est obtenue par une pose dans le plan frontal pres de la position neutre (11) avec un petit raccourcissement Dans le plan sagittal la marche et le confort de la position assise etaient les meilleurs lorsque l angle de flexion de la hanche etait de 45° (mesure de la position zero jusqu a pleine extension)

Les résultats furent entirerement conformes aux valeurs théoriques ressortant d une analyse des mecanismes de la mobilite de la colonne lombaire et de la hanche saine apres arthrodese

## ZUSAMMENFASSUNG

Die Stellung die für die Huftarthrodese in der Literatur emphohlen wird ist von den einzelnen Verfassern weit verschieden angegeben worden Metoden zur Messung der Stellung einer stifen Hufte werden selten mitgeteilt und diejenigen welche veroffentlicht wurden sind ungenau

Bei 35 Patienten die eine Hüftarthrodese hatten wurde die Beziehung

zwischen der Hüftstellung, dem Gang und der Bequemlichkeit im Sitzen untersucht. Die Messungstechnik zur Bestimmung der Stellung der steifen Hüfte wird beschrieben. Die Ergebnisse zeigen, dass die Rotationsstellung scheinbar hinsichtlich der Funktion von geringerer Bedeutung ist und dass der beste Gang mittels Einstellung in der Frontalebene nahe der "neutralen Position" (11) mit geringer Verkürzung erzielt wird. In der Sagittalebene war der Gang und die Bequemlichkeit im Sitzen am besten, wenn der Beugungswinkel der Hüfte 45° war (gemessen von der Nullstellung bei voller Extension).

Die Ergebnisse waren in genauer Übereinstimmung mit den theoretischen Werten, die von einer Analyse der Bewegunsmechanik der Lendenwirbelsäule und der gesunden Hüfte nach Arthrodese erhalten wurden.

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From the Orthop Clinic Lund Sweden
(Head Professor Gunnar Wiberg)

# SYNOVIAL OSTEOCHONDROMATOSIS OF THE HIP

*(Report of 8 Cases Including 2 in Brothers)*

*By*

BJORN M PERSSON

Received 15 IX 65

Synovial osteochondromatosis is a fairly uncommon condition and is seldom seen in the hip It was therefore thought that a report on the following 8 cases would be justified especially since 2 of them were seen in brothers and at least one of the other cases had been precipitated by rheumatic fever

It appears that *Reichel* (1900) was the first to describe the condition which he saw in an operated knee (16) where it is 10 times more common than in the hip So far some 40 cases of synovial osteochondromatosis of the hip are on record (17) None of the series described however consisted of more than 5 cases The process consists of cartilage and bone formation in a lobulated and multicentric fashion within a synovial tissue The bodies thereby formed become calcified pedunculated and even detached and released into the joint as the disease progresses (8) The condition is conceived as neoplastic (Lexer) or metaplastic All attempts to ascertain whether infection or trauma can cause the condition have hitherto failed Apart from trivial everyday trauma the onset is rarely antedated by any known traumatising accident Histologically inflammation most likely abacterial is invariably seen in fresh cases (8 9) Most recent authors believe the bodies probably formed from embryonic rests in the synovial tissue Such rests have been shown to occur (8 15 19)

The possibility of the lesions being neoplastic is supported by a case reported by *Nixon Frank Chambers* in 1960 (13) Their patient a man was operated upon for microscopically confirmed osteochondromatosis One year later the site of the operation was found to harbour a sarcoma for which the patient was subjected to hindquarter amputation This patient might have had a sarcoma and not

osteochondromatosis from the very beginning for it is the only case on record that turned out to be malignant As a rule the process is self limiting (3 21) non recurrent (17) non invasive and monoarticular It has been shown roentgenographically that single calcified bodies occasionally disappear spontaneously One polyarticular case affecting the knee ankle and elbow has been reported (5)

Osteochondromatosis of the hip is considerably more common in males than in females and has been seen in patients of all ages above 13 years

During the last 20 years synovial osteochondromatosis of the hip has been seen at the orthopedic department in Lund in 8 patients including 2 brothers

## CASE REPORTS

*Case 1* A girl aged 15 complained of 3 to 4 years aching pain in the left thigh with progressive loss of range of motion of the joint No known trauma In the years before she had had *scarlet fever twice* Roentgenographic examination revealed osteochondromatosis of the hip joint E S R was normal Operation with excision of the bodies and partial synovectomy confirmed the diagnosis When last seen at 21 6 ears after the operation the patient was still free from pains in spite of slightly reduced range of motion The X ray picture showed no recurrence

*Case 2* A man aged 31 had for 4 years complained of disabling aching pain and stiffness of the right hip Infection or trauma not known Repeated roentgenographic examination and biopsy to check the possibility of tuberculosis revealed unspecific synovitis only He was then 29 Repeated determinations of the E S R were invariabl normal When he was 31 another biopsy revealed the nature of the condition and the findings at the later synovectomy confirmed the diagnosis Two free chondromas were also found in the joint At 3? arthrodesis was performed because of the continuing pains and at 39 the roentgen picture showed no recurrence of the synovial calcifications

*Case 3* The patient was a man aged 33 At 13 he had otitis Three weeks later he was admitted to hospital because of fever with peaks of 41 C, increased E S R (100 mm/1 hr ) and pain in several joints especially in the left hip He spent 2 months in hospital after which he was symptomfree apart from a feeling of slight stiffness of the left hip Roentgen examination one month after he had left hospital showed some slight skeletal rarefaction of the hip but not the picture of osteochondromatosis At examination one month after he had left hospital the E. S R. and the range of mobility of the hip were judged as normal but the patient says that he has never been free from stiffness of that hip since then The condition had been diagnosed as *rheumatic fever* The patient returned to his work on a farm and did not seek a doctor again until the age of 33 when an examination including roentgenography of the left hip for military service revealed the picture of a long standing sclerotic multicentric typical synovial osteochondromatosis (Figure 1)



*Figure 1* *Synovial osteochondromatosis as seen 20 years after the first symptom during rheumatic fever in a 13 years old boy (case 3)*

The range of mobility of the hip was only 50 per cent of normal and the quadriceps was severely atrophied A lump was felt in the groin Deforming osteoarthritis of the femoral head and acetabulum was also noted (Figure 1) Operation confirmed the diagnosis as did microscopy

*Case 4* The patient was a man aged 35 who had for 9 years had progressive weakness stiffness and aching pain of the left hip No specific trauma no infection known Repeated roentgenographic examination had failed to reveal any calcified bodies Repeated determinations of the E S R had invariably been normal Arthrography had not been done Roentgenographic examination 9 years after the onset of symptoms revealed the characteristics of synovial osteochondromatosis The patient had moved to another hospital region

*Case 5* The patient was a man aged 40 At 15 he had been diagnosed as having coxa plana Ten years later he sought treatment for progressive stiffness of that hip The E. S R was normal Infection or trauma was noted Roentgenographic examination revealed typical synovial osteochondromatosis and a slight coxa plana deformity of the femoral head When last seen another 14 years later he was then 40 and the roentgen appearance of the hip was unchanged The patient is still at work without pain and operation is not accepted

*Case 6* The patient was a man aged 81 Suspected osteochondromatosis of the hip was discovered incidentally at roentgen examination after a minor traffic accident The hip was not painful but its range of motion was slightly decreased The E S R was normal Operation is not indicated the diagnosis is not confirmed

*Case 7* The patient was a man aged 45 At 26 he had had *tonsillitis with glomerulonephritis* treated in hospital and at 40 he had a ureteric stone which passed spontaneously He reported that for 5 years he had had aching pain and stiffness of the right hip He could not remember any trauma During these years *he had been examined repeatedly and had received various courses of physio*therapy His working capacity was considerably reduced The E S R had been determined on 7 occasions and had always been normal AST and ASTA were



*Figure 2 Case 7 Continuing hip pain in a 43 years old man as seen two years after the first symptom still no calcification in the synovia*

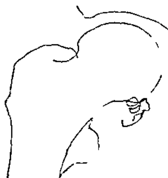




*Figure 3 Case 7 Seven months later two and a half years after the first [illegible] non diagnostic calcifications are visible*



*Figure 4 Case 7 Another 11 months later three years after the beginning of continuing hip pain Synovial osteochondromatosis probable and confirmed by operation*

negative Roentgenography had shown some rarefaction but not the picture of osteochondromatosis (Figure 2) Tuberculosis was considered Three years after the onset of the symptoms calcification was observed for the first time (Figure 3) The stiffness of the joint had not progressed during the last 2 years Operation was performed one year later (Figure 4) with subtotal synovectomy The excised tissue weighed 130 gm The microscopic picture of the tissue was typical of osteochondromatosis

*Case 8* The patient was a man aged 48 He was the brother of the patient in case 7 At 38 the right hip became painful The pain had not been preceeded by any known trauma or infection Three months later by which time the pain was incessent he was admitted to hospital for examination Roentgenographic examination revealed nothing remarkable The F S R was normal A biopsy specimen was removed via a short Langenbeck incision The joint capsule which was of

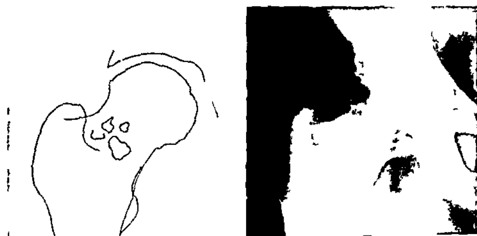


*Figure 5 Case 8 A 38 years old man with hip pain since half a year Non diagnostic calcifications in the soft tissue tuberculous was suspected*

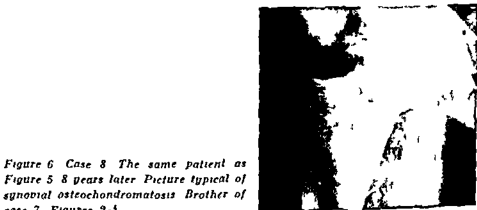


*Figure 6 Case 8 The same patient as Figure 5 8 years later Picture typical of synovial osteochondromatosis Brother of case 7 Figures 2-4*

normal gross appearance showed histological evidence of villous hyperplasia with perivascular lymphocytes and histiocytes but no specific elements The pathologist's report was non specific inflammation Roentgenographic examination 3 weeks later revealed for the first time a typical calcification (Figure 5) Arthrography was not performed Body temperature E S R. were normal and the clinical picture was unchanged. One year later the patient returned to work the hip was then less painful but still somewhat stiff Seven years later the patient's brother was found to have osteochondromatosis and then the patient was re examined again and this time roentgenography revealed the synovial osteochondromatosis (Figure 6) Deforming osteoarthrosis which is sometimes seen in synovial osteochondromatosis was not seen Operation is planned mainly because of the severe limitation of mobility of the joint

## DISCUSSION

The occurrence of synovial osteochondromatosis in two brothers suggests the possibility of some familial factor in the causation of the disease These two patients belonged to a sibship of 7 members (5 males and 2 females) Physical and roentgenological examination of the brothers and sisters revealed nothing remarkable apart from recurrent spells of pain in the left hip of one of the males At the examination this man was treated with penicillin and had a registrable limitation of motion range of one hip although neither plain roentgenography nor contrast arthrography (Urografin) showed anything abnormal Inquiry into the familial history of the remaining 6 cases in the series revealed nothing of interest

*Figure 7 The authors material from the Orthopaedic Clinic in Lund 1945–65*

| Case No | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Age at diagnosis | 15 | 31 | 33 | 35 | 40 | 81 | 45 | 48 |
| Male | — | + | + | + | + | + | + | + |
| Female | + | — | — | — | — | — | — | — |
| Durations of symptoms before diagnosis in years | 3.5 | 4 | 20 | 9 | 14 | — | 5 | 10 |

Although examination did not reveal osteochondromatosis in a third member of the sibship and though familial occurrence has never before been described the possibility of some familial factor in the causation of osteochondromatosis cannot be excluded The members of this family showed a tendency to obesity but were all healthy There was no heredity of allergy or collagenosis nor was any other joint disease known in the family

In all the 8 cases the diagnosis of synovial osteochondromatosis had

been preceded by several years of hip trouble sometimes very disabling (Figure 7) All of the cases had finally been diagnosed by roentgenography As is known in suspected cases the diagnosis can be demonstrated earlier by contrast arthrography (18) It was noteworthy that in seven of the eight patients the E S R was invariably found normal At the time of roentgenographic diagnosis all were normal This argues against an active infectious coxitis and rheumatoid arthritis in a patient seeking attention for hip pains If plain roentgenography shows no evidence of deforming osteoarthritis and the unexplained pain continues for many months the cause may be a synovial chondromatosis and arthrography should be considered

Finally by documented patient history case n o 3 shows that the hip affection of a rheumatic fever may lead to synovial osteochondromatosis Further one other patient (case 7) had had glomerulonephritis several years before the diagnosis of osteochondromatosis and case 1 had a record of scarlet fever twice It all indicated that non suppurative complications of streptococcal infection might be the start of a process which years later is diagnosed as synovial osteochondromatosis in a period when the E S R is normal Maybe the weak familial factor in question is a tendency for this immunological reaction to a streptococcal infection

## SUMMARY

A short review of the literature is given the characteristics of the disease are described Eight new cases are presented including two brothers whose brothers and sisters were examined In one of the eight cases described the disease seems to have started as a rheumatic fever and non suppurative complications of streptococcal infections are discussed as a causative mechanism in certain cases

## RESUME

*Il est donne un aperçu de la littérature Les traits caracteristiques de* la maladie sont decrits Huit nouveaux cas sont presentes y compris deux freres dont les freres et soeurs furent examines Dans l un des huit cas décrits la maladie semble avoir debute par une fievre rhumatismale Il est discute de complications non suppuratives d infections streptococciques comme d un mecanisme causatif dans certains cas

## ZUSAMMENFASSUNG

Eine kurze Übersicht über die Litterature wird gegeben und die Kennzeichen der Erkrankung werden beschrieben Acht neue Falle werden vorgestellt einschliesslich zweier Bruder deren Brüder und Schwestern untersucht wurden In einem der beschriebenen Falle hat die Krankheit scheinbar als rheumatisches Fieber begonnen Nicht suppurative Komplikationen von Infektionen mit Streptokokken werden als Ursache in gewissen Fallen besprochen

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Acta orthop Scandinav 37 94–106 1966

From the Department of Orthopaedics (Head L. Hult) University of Umeå

# THE SCREW HOME MOVEMENT IN THE KNEE JOINT

By

L C HALLEN and O LINDAHL

Received 8 III 65

The modern textbooks almost invariably make some reference to the screw home movement in the knee joint "The medial condyle is ½ in longer than the lateral condyle which permits the femur to screw home on full extension and this stabilizes the joint (*Bailey* (1)) The movement of medial rotation of the femur on the tibia associated with the later stages of extension of the knee consitutes a locking mechanism which is an asset when the knee is subjected to strain (Gray's Anatomy (6)) The screw home phenomenon made possible by the prolongation of the anterior portion of the articular surface of the medial condyle is the most important factor in stablization of the knee in extension (*De Palma* (7)) The key to the function of the knee joint and to its derangements is the rotation of the tibia on the femur which occurs on flexion and extension movements (*Helfet* (4)) The screw home movement is probably the key to the mechanism of the common meniscus lesion and as will be shown probably the key to the common lesion of the anterior cruciate ligament also (*Smillie* (10))

All these authors point to the importance of the screw home movement in various respects but no explanation of its mechanism is offered In fact no exact account of the measurement or registration of the movement is to be found it is usually pointed out simply that such a rotation must of necessity occur because the medial condyle of the femur is longer than the lateral one *Helfet* (5) states that in the last 10 of extension the tuberosity of the tibia can be seen to move laterally If reference to the terminal rotation is traced back in the literature it is found that Virchow was among the first to point out its existence In a major contribution on the mechanics of the knee joint *Meyer* (9) made a careful analysis of the movement He seems not to have made any direct study of the occurrence of a terminal rotation in the joint but bases his views on a long and in part quite involved reasoning on

the anatomy and mechanics of the joint. Broadly speaking his explanation of the terminal rotation is that the medial condyle of the femur is longer than the lateral and moreover curved with the convexity facing the intercondylar eminence.

*Fick* (8) observed the screw home movement in patients and specimens but gives no details of his material or methods of measurement. He criticises Meyer's theory that the rotation is effected by the articular surfaces and considers that the structure of the ligaments in the knee, especially the structure of the cruciate ligaments, is bound to produce an outward rotation of the tibia when the knee is extended fully. According to Fick the form of the articular surfaces would be a consequence rather than a cause of the terminal rotation.

In the more recent discussions of the screw home movement Meyer's and Fick's information on the existence and magnitude of the movement (an outward rotation of 5–10°) seems to be accepted without question.

The object of the present study is to examine the nature of the screw home movement by experiments on a fairly large number of joints without reliance on mechanical arguments and earlier observations which form the basis for the prevailing views on the rotation. In this connection it was found that it was difficult to record accurately the small rotational movements of the lower leg when the knee was extended, and even when this could be managed by means of an angle measuring device there remained the difficulty of preventing simultaneous rotation of the femur in the hip joint. An attempt to overcome these difficulties was made by suitable choice of material and method.

## NOMENCLATURE

For the purpose of this study *extension* is defined as the position in which the knee joint is fully extended and presents resistance to further extension, whether this is in the 180° or 190° positions. *Outward* or *inward rotation* of the knee joint is the movement described by the tibia about its axis in relation to the femur. When the knee is flexed the femur cannot rotate about its axis in relation to the tibia. The flexed knee can be rotated both actively and passively. Since a passive rotation is possible in extension (*Hallén & Lindahl* (3)) and, as will be evident from the results reported below, sometimes also an active one, it is necessary when measuring the rotation that occurs between a flexed and an extended position to define accurately the initial positions in

respect of rotation in both flexion and extension A distinction will be drawn between active and passive rotation

## MATERIAL

1 Autopsy specimens 16 knee joints
2 Hip arthrodesis cases

(a) Eleven knee joints of patients with a nail arthrodesis performed on the hip of the same side 2–3 weeks earlier
(b) Three knee joints with an arthrodesis provided several years previously

3 Surgical cases Ten knee joints of patients anaesthetized for operations on a lower extremity not including the knee joint

The age and sex distributions are shown in the Tables 1–3 Except in the cases of old hip arthrodesis the knee joints were normal apart from the chondromalacia and osteoarthritis that is usual among older people The joints of the patients with a fresh arthrodesis had been normal before the operation and had not been put in plaster nonetheless there was usually a moderate restriction of flexion

## METHODS

In all the above knee joints a determination was made of the angle through which the tibia could be rotated in 160 flexion and extension and the changes in rotation that could be produced actively and/or passively in the movement from the former to the latter positions

On the *autopsy specimens* a special angle measuring device was used that has been described elsewhere (3)

On the *hip arthrodesis cases* rotation of the femur was prevented An instrumen for measuring the angle—different in design from that used on the autopsy specimens—was attached to the lower leg (Figure 1) This gives correct values only when it is held vertically and requires the lower leg to be kept horizontal while the position of the femur and the body is altered by tilting the table The *passive* rotation accompanying extension of the joint was measured in the following ways (Figure 2)

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| (*i*) | Maximum inward rotation at 160 to maximum inward rotation in extension (In—In) | | | | | | | | | |
| (*ii*) | Maximum (In—Out) | „ | „ | „ | „ | „ | outward | „ | „ | „ |
| (*iii*) | Maximum outward (Out—In) | „ | „ | „ | „ | „ | inward | „ | „ | „ |
| (*iv*) | Maximum (Out—Out) | „ | „ | „ | „ | „ | outward | „ | „ | „ |

In addtion the rotation occurring in *active* extension was measured The patient was then required to assume an arbitrary rotation position at 160 and with the knee fully extended

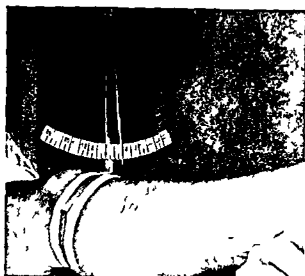


*Figure 1 Apparatus for clinical measurement of the rotation of the tibia*

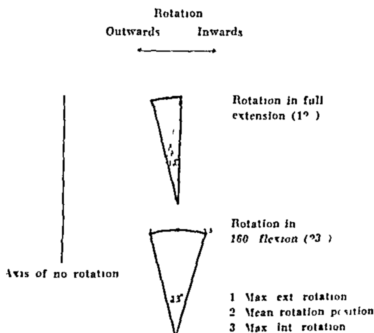



*Figure 2 Diagram of the range of rotation of the knee joint in extension (upper) and the 160 position (lower) The broken lines show how the knee joint can be rotated in different ways during the terminal extension*

In the 10 *operation cases* Kirschner wires had been inserted in the femoral and tibial condyles from the lateral aspect near the knee joint to serve as indicators The change in angle between them measured in the longitudinal direction of the tibia was then determined as the lower leg was rotated passively in the 160 position and in extension The rotation was also measured during extension for th same 4 changes in position as in the arthrodesis cases Finally the "spontaneous" terminal rotation was measured during extension in the 160 position a relaxed more or less arbitrary neutral position was used and the leg was allowed to hang freely in extension supported onl under the heel

## RESULTS

*Autopsy specimens*—In extension rotations of between 2 and 18 mean 11 were recorded In the 160 position the range was 17–35 mean 25

Both inward and outward rotations could be produced during the extension movement depending on the initial and final rotation positions The exact values for these rotations were not measured on the autopsy specimens On extending the knee from an arbitrary rotation position in 160 by lifting under the heel an outward rotation ranging from 1 to 14 was recorded The magnitude of the rotation observed in these autopsy specimens has been reported in detail elsewhere (3)

*Arthrodesis patients*—The recorded rotation values are given in Table 1

*Table 1 Knee joint rotation for patients with newly performed hip arthrodesis Positive values denote outward and negative values inward rotation*

| Sex | Age | Rotation in extension | Rotation in 160 | In–In | In—Out | Out—In | Out Out | Active rotation |
|---|---|---|---|---|---|---|---|---|
| F | 55 | 12 | 20 | 8 | 18 | —13 | 0 | 6 |
| M | 56 | 7 | 18 | 11 | 18 | — 6 | 0 | 14 |
| F | 64 | 4 | 16 | 10 | 14 | — 5 | — 2 | 2 |
| F | 58 | 7 | 15 | 8 | 14 | — 5 | 0 | 12 |
| F | 44 | 13 | 20 | 7 | 25 | —22 | 0 | 7 |
| F | 62 | 5 | 10 | 5 | 15 | — 4 | 0 | 10 |
| F | 6 | 10 | 15 | 6 | 17 | —10 | 1 | 0 |
| F | 44 | 9 | 13 | 6 | 16 | — 6 | 2 | 8 |
| M | 61 | 12 | 21 | 8 | 27 | —18 | — 1 | 8 |
| M | 61 | 13 | 38 | 8 | 21 | —30 | —20 | 5 |
| M | 60 | 14 | 22 | 10 | 23 | —15 | 2 | 5 |
| Mean | | 10 | 19 | 8 | 19 | —12 | — 2 | [illegible] |

See *Methods* (i) – (iv)

The mean range of *passive* rotation in passive extension was 10. The average screw home movement was 12 inwards for the tests from the outward to the inward positions and 19 outwards for the tests from the inward to the outward positions. A mean outward rotation of 7 was obtained for *active* extension from 160 with an arbitrary initial rotation position.

*Table 2. Knee joint rotation in patients with hip arthrodesis supplied several years previously. Positive values denote outward and negative values inward rotation*

| Sex | Age | Rotation in extension | In-In | In—Out | Out—In | Out-Out | Spont rotation | Active rotation in ext |
|---|---|---|---|---|---|---|---|---|
| F | 60 | 20 | 14 | 28 | —24 | —6 | variable | 5 |
| F | 55 | 26 | 15 | 42 | —16 | 10 | 14 | – |
| F | 61 | 31 | 16 | 38 | —18 | 15 | 5 | 6 |

*Table 3. Rotation in the knee joint in operation cases. Positive values denote outward and negative values inward rotation*

| Sex | Age | Rotation in extension | Rotation in 160 | In-In | Out-Out | Spont rotation |
|---|---|---|---|---|---|---|
| F | 20 | 20 | 26 | 9 | — 5 | 5 |
| F | 56 | 10 | 30 | 7 | —19 | 7 |
| M | 65 | 14 | 27 | [illegible] | —18 | 0 |
| M | 11 | 12 | 30 | 4 | —10 | 6 |
| F | 56 | 13 | 9 | 20 | — 8 | 20 |
| F | 17 | 18 | 21 | 17 | — 1 | 6 |
| F | 58 | 15 | [illegible] | 6 | — 4 | 6 |
| F | 51 | 13 | 20 | 5 | — 2 | 5 |
| F | 55 | 13 | 32 | 20 | —10 | 8 |
| M | 44 | 17 | 20 | 0 | — 1 | 7 |
| Mean | | 15 | 24 | 10 | — 8 | 7 |

The values for patients whose arthrodesis had been supplied several years previously are given in Table 2.

Although this is a fairly small group there is convincing evidence that the functional demands associated with the hip arthrodesis result in stretching of the capsule and ligamental apparatus of the knee with

See Methods (i) - (ii)

a consequent reduction in the joint s stability and an increase in its range of rotation in different positions In 2 of the cases also an active rotation was recorded in extension For this reason the main study was performed on patients supplied with an arthrodesis within the previous 2–3 weeks during which period it is unlikely that there could have been any appreciable alteration in the stability of the joint

*Operation cases*—The rotation values are shown in Table 3

The mean rotation in extension was 15 and in the 160 position 24 As in the arthrodesis cases both inward and outward rotation could be obtained passively on extending the joint In passive extension from an arbitrary neutral initial position in 160 flexion a mean outward rotation of 7 was recorded

## DISCUSSION

It seems to be generally accepted that the knee joint cannot be rotated in extension but is necessarily locked by the screw home movement

*Brantigan et al* (2) and *Akerblom* (11) have spoken of a rotation in extension they alone report values of between 2 and 10 In an earlier study (3) on autopsy specimens the present authors recorded a mean rotation of 11 in extension This has been confirmed in the present study on a series of patients with hip arthrodeses and on operation cases where the range of the movement could be measured to an acceptable level of accuracy This rotation which was obtained passively averaged 12 Active rotation of the extended joint is extremely difficult to measure When the quadriceps is under powerful tension it seems that an active rotation is difficult if not impossible to obtain In some of the patients with an old hip arthrodesis however active rotation was in fact recorded in this position

The *active* screw home movement obtained in the arthrodesis cases would appear to confirm the view that extension ends with an outward rotation The mean value was 7 It must be borne in mind that the degree of rotation in the flexed joint can to some extent be influenced and that this is possibly the case also in extension Thus this outward rotation can be more or less prevented by will power

Of the obligatory *passive* screw home movement mentioned in the literature there was no evidence in this material Depending on the position of rotation both in 160 flexion and in extension it was possible to obtain passively an outward or an inward rotation or no rotation at all As Figure 2 shows however the "mean rotation position was

further outward in extension than it was at 160 a difference that is possibly due to the shape of the condyles the arrangement of the ligaments or to both

In the light of these results it is difficult to accept the obligatory screw home movement as a physiological fact and likewise to see its significance as regards the stability of the knee joint or the mechanics of various kinds of injuries to the joint

## SUMMARY

The screw home movement is considered to be an important feature of the mechanics of the knee joint It would seem that the existence of such a movement has never been proven and no measurements of it have been reported On 37 normal knee joints an examination was made of the rotation in maximum extension and the 160 position and of changes in the rotation between these positions In maximum extension a mean rotation of 12 was recorded and in 160 a mean of 23 In active extension or when the knee is passively extended from 160 an outward rotation of about 7 was usually found this would appear to confirm the prevailing view on a screw home movement

If however a conscious effort was made to rotate the lower leg during the extension movement either an outward or an inward rotation could be obtained Thus it was not possible to confirm the presence of an obligatory passive screw home movement which cannot therefore be ascribed particular significance in the mechanics of the knee joint

## RESUME

Le mouvement de vis est considere comme un important element des mecanismes de l articulation du genou Il est vrai que l existence d un tel mouvement n a jamais ete prouve et qu aucune mensuration n a ete rapportee Sur 37 articulations normales du genou on a examine la rotation en position d extension maximum et dans la position de 160 ainsi que les changements de rotation entre ces deux positions En position d extension maximum une rotation moyenne de 12 a été enregistree et en position de 160° une moyenne de 23 Dans l extension active ou lorsque le genou est en etat d extension passive de 160 une rotation en dehors d environ 7 a generalement ete trouvee cela semble confirmer le point de vue du mouvement "de vis

Si neanmoins un effort conscient etait fait pour tordre la partie infe

*rieure de la jambe durant le mouvement d'extension* il ne pourrait être obtenu ni une rotation en dehors ni une rotation en dedans Il n'est donc pas possible de confirmer la presence du mouvement de vis obligatorement passif auquel on ne peut par consequent pas attribuer une signification particuliere dans les mechanismes de l'articulation du genou

## ZUSAMMENFASSUNG

Die abschliessende *Schraubenbewegung wird als ein wichtiges Ge*schehen in der Mechanik des Kniegelenkes angesehen Es scheint dass das Vorhandensein einer solchen Bewegung niemals bewiesen worden ist und uber keinerlei Messungen derselben ist berichtet worden An 37 normalen Kniegelenken wurde eine Untersuchung der Rotation bei maximaler Streckung under der 160 Stellung sowie von Veranderungen der Rotation zwischen diesen Stellungen vorgenommen Bei maximaler Streckung wurde eine Durchschnittsrotation von 12 verzeichnet und in der 160 Stellung ein Durchschnitt von 23 Bei aktiver Streckung oder wenn das Knie passiv von 160 gestreckt wird wurde gewohnlich eine Auswärtsrotation von 7 gefunden Dies scheint die vorherrschende Meinung dass eine Abschlussschraubenbewegung besteht zu betätigen Wenn jedoch eine bewusste Anstrengung gemacht wurde den Unterschenkel wahrend der Streckung zu rotieren konnte weder eine Auswarts oder Einwärtsrotation erhalten werden Es war daher nicht möglich das Vorhandensein einer obligatorischen passiven abschliessenden Schraubenbewegung zu bestätigen und man kann ihr daher keine besondere Bedeutung in der Mechanik des Kniegelenkes zuschreiben

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From the Department of Surgery of the Extremities The Centralhospital Næstved Denmark (Chief surgeon Jørgen Falkenberg M D )

# DISLOCATION OF THE UPPER END OF THE FIBULA

*By*

STEEN CHRISTENSEN

Received 24 IV 65

It is seldom that one sees dislocation in the superior tibio fibular joint It may occur as an isolated injury or combined with fracture of the fibula and with dislocation in the inferior tibio fibular joint

An isolated dislocation was first described by *Nelaton* (1874) and a comprehensive review given by *Lyle* (1925) while a detailed description of anatomy clinical features and treatment was given by *Harrison & Hindenach* (1959) in connection with 5 case reports

In Scandinavian literature no cases have been reported and on enquiring at the larger Danish hospitals no cases were found The lesion is briefly mentioned in the larger text books (*Shinz et al* (7)) *Lyle* has collected 42 cases from the literature and he concludes that dislocations are directed anteriorly twice as often posteriorly Upward dislocations cannot occur in an isolated manner but occur with fractures of fibula or dislocations in the ankle joint Dislocations are not always caused by trauma Non traumatic dislocations or subluxations are seen after half leg amputations or in patients with strained ligaments

In the cases where the patients are aware of the way in which the trauma occurred they often say that they have fallen with one leg extended and the other bent behind it as may happen to football players and other sportsmen (1 8) Parachutists are trained to land with the feet together and the knees slightly flexed They may be blown sideways and have one leg forced behind the other *Lord & Coutts* (4) have investigated 250 000 jumps and found a group of "silent fractures in the upper third of fibula or less frequently a dislocation of the fibular head

Some cases occur of multiple lesions and fractures (1) A few cases are reported as nontraumatic when the patient rose from a kneeling

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ralement facile consiste en une réduction f[illegible] cas une reduction ouverte avec fixation est n[illegible]

## ZUSAMMENFASSUNG

Verrenkungen des proximalen tibio-fibularen [illegible] und Luxation nach vorne findet sich am häufi[illegible] im allgemeinen einfach besteht in der unblutig[illegible] einigen wenigen Fallen ist die offene Einr[illegible] notwendig

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From the Orthopaedic Hospital of the Invalid Foundation Helsinki Finland
(Head Professor A Langenskiöld M D )

# CHOPART, PIROGOFF AND SYME AMPUTATIONS

*A Survey of Twenty one Cases*

*By*

CASTOR LINDQVIST AND ERIK B RISKA

Received 19 V 65

The latest developments in the fields of biophysics and prosthetics especially in the use of stump sockets of laminated plastics instead of leather have revived interest in Chopart s Pirogoff s and Syme s amputations which have been in use for over a hundred years Syme s amputation in particular has aroused attention in recent decades (1 2 3) These amputations however are performed relatively seldom to day Perhaps below knee amputation is far too often preferred to surgery at ankle level or foot injuries are treated conservatively at the cost of repeated operations and long hospitalization in order to preserve as much as possible

The study concerns amputees fitted with new types of prostheses by the Prosthetic Shop at the Orthopaedic Hospital of the Invalid Foundation (Helsinki) since 1961

## MATERIAL

The material comprises 25 patients fitted with prostheses at the shop A follow up examination was made of the 19 patients who came when invited (Table 1) Since two of them were bilateral amputees the number of stumps was 21

It should be emphasized that the material was heterogeneous The following facts varied lesions prior to surgery the patient s age at the time of amputation and of the follow up examination (Table 2) the patients experience in the use of prosthesis etc As a result only a few general conclusions can be drawn from the results of the investigation

Table 3 indicates the time in years from the amputation to the latest examination Most of the Chopart and Pirogoff amputees were veterans of World War II and most of the Syme cases were of fairly recent date

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Paper read at the 32nd Congress of the Scandinavian Orthopaedic Association in Helsinki 23 27th June 1964

*Table 1*

| Type of amputation | No of cases | Bilateral | Male | Female |
|---|---|---|---|---|
| Syme | 11 | 1 | 5 | 5 |
| Pirogoff or Boyd | 4 | | 3 | 1 |
| Chopart | 6 | 1 | 4 | 1 |
| Total | 21 | 2 | 12 | 7 |

*Table 2 Age at Time of Amputation*

| Age<br>Years | Syme<br>*No of cases* | Pirogoff or Boyd<br>*No of cases* | Chopart<br>*No of cases* |
|---|---|---|---|
| 2 | 1 | | |
| 20 – 30 | 2 | 3 | 4 |
| 31 40 | 4 | 1 | 1 |
| 41 – 60 | 3 | | 1 |
| over 61 | 1 | | |
| Total | 11 | 4 | 6 |

*Table 3 Time from Amputation to Last Follow up Examination*

| Time<br>Years | Syme<br>No of cases | Pirogoff or Boyd<br>No of cases | Chopart<br>No of cases |
|---|---|---|---|
| 1 | 3 | | |
| 1 – 2 | 2 | | 1 |
| 2 – 3 | 3 | 1 | 1 |
| 3 – 4 | 3 | | |
| 4 – 5 | | 1 | |
| 19 – 2 | | 2 | 4 |
| Total | 11 | 4 | 6 |

## RESULTS

At the follow up examination special attention was paid to two main aspects

1 the condition of the stump

2 the functioning of the prosthesis

The location of scars tender points callosities the consistency of

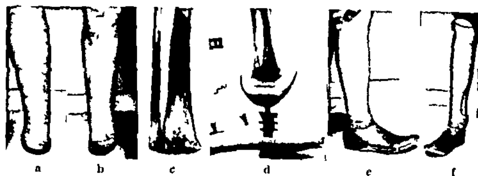



*Figure 1 Male retired truckdriver born 1903 Syme amputation performed in 19?? owing to arteriosclerotic gangrene The stump is good but somewhat sensitive to cold Wears a prosthesis of laminated plastics medial opening at the ankle and SACH foot Function is good*
a and b stump c x ray of the stump
d x ray through the prosthesis e and f prosthesis




*Figure 2 Female housewife born 19?7 Chopart amputation in childhood owing to foot gangrene after scarlet fever A Syme stump was made in 19?0 after persistent discomfort in the use of a prosthesis Patient fully approves of the new prosthesis the stump is perfect and the function good*
a and b stump c x ray of the stump
d x ray through the prosthesis e and f prosthesis

the plantar skin and the shape of the stump were noted The range of movement of the talocrural joint of the Chopart stumps was measured X rays were taken without the prosthesis and with the prosthesis bearing the patient s weight

A stump was considered good if it was faultless in every respect fair if it had only one major defect and poor if several defects were found (Table 4)

The functioning of the stump and the prosthesis were estimated by means of interviews with the patients They were asked about the

use of a prosthesis at home and at work discomfort during weight bearing sensitiveness to cold the care they took of the stump and their opinions on further improvements of their prostheses In each case the classification of the result as good fair or poor was based

*Table 4 Results of Surgery*

| Amputation stump | Syme No of cases | Pirogoff or Boyd No of cases | Chopart No of cases |
|---|---|---|---|
| Good | 8 | 4 | 3 |
| Fair | 2 | | 1 |
| Poor | 1 | | 2 |
| Total | 11 | 4 | 6 |

*Table 5 Functional Results*

| Function of stump and prosthesis | Syme No of cases | Pirogoff or Boyd No of cases | Chopart No of cases |
|---|---|---|---|
| Good | 9 | 4 | 2 |
| Fair | 2 | | 1 |
| Poor | | | 3 |
| Total | 11 | 4 | 6 |



*Figure 3 Male industrial draughtsman born 1920 Stepped on a mine in 1941 and Chopart amputation was performed A Pirogoff stump was made in 1959 because of persistent discomfort and difficulty in obtaining a proper prosthetic fit The patient wears a prosthesis with a non tibial condyle bearing socket of laminated plastics and with a SACH foot Function is good*

a and b stump c x ray of the stump

d x ray through the prosthesis e and f prosthesis

## RÉSUMÉ

1 Les amputations selon Syme ont généralement comme résultat un moignon consolidé auquel il est facile de fixer maintenant une prothèse fonctionnelle

2 Les amputations selon Pirogoff (& Boyd) semblent donner des moignons comparables à ceux de Syme Une soudure défectueuse entre l'os calcaneum et le tibia est toutefois une complication possible bien qu'elle n'apparaissait pas avec évidence dans les cas examinés

3 Les amputations Chopart ont souvent comme résultat un moignon inconfortable auquel il est difficile de fixer une prothèse

## ZUSAMMENFASSUNG

1 Syme Amputationen ergeben im allgemeinen verlässliche Stümpfe die nunmehr leicht mit einer funktionellen Prothese versehen werden können

2 Pirogoff (und Boyd) Amputationen scheinen Stümpfe zu hinterlassen die Symes Stumpfen vergleichbar sind Mangelhafte Vereinigung zwischen Calcaneus und Tibia ist jedoch eine mögliche Komplikation obwohl dies nicht in den untersuchten Fällen beobachtet wurde

3 Chopart Amputationen ergeben oft unbequeme Stümpfe und sind schwierig mit Prothesen zu versorgen

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From the Orthopaedic Department (Head Anders Hulth M D) Malmo Allmanna Sjukhus and the Orthopaedic Department (Head Professor Tor Hiertonn M D) Akademiska Sjukhuset Uppsala Sweden

# ACID BASE STATUS OF THE INTRAMEDULLARY BLOOD IN IMMOBILIZED EXTREMITIES

*A Preliminary Report*

*By*

ANDERS HULTH and HELGE SEMB

Received 27 viii 65

When an extremity is immobilized osteopenia appears in the bone tissue and atrophy in the musculature This is a generally known fact which has been the subject of much research It is commonly believed that immobilization leads to circulatory stasis with reduction of the pH and that the increased acidity favours increased bone resorption (*Neuman & Neuman* 1958 *Nordin* 1960) But it has been shown that the rate of new bone formation appears to be normal in immobilization (*Engstrom & Amprino* 1950 *Slack* 1954 *Heaney & Whedon* 1958) The resorption on the other hand is increased which explains the loss of bone substance

The present investigation was carried out in order to demonstrate possible changes in the acid base status of the intra-osseous blood from an immobilized extremity The blood was obtained from holes drilled into the marrow cavity of the tibia near the distal metaphyseal area This blood is a composite blood containing arterial capillary (from the sinusoids) and venous blood (from the great collecting vein in the centre of the marrow canal) It is not the blood which is in closest contact with the bone surfaces where resorption takes place or new bone is formed but it would seem to be closely related to this blood We have no exact knowledge as to the cortical flow in the diaphysis of a long bone but it is possible that the direction of flow through the vascular canals of the cortex varies according to whether the musculature is at rest or at work (*Valderrama & Trueta* 1965) The blood which reaches the marrow cavity via the nutrient artery has a constant direction of flow but varies in quantity

## MATERIAL AND METHODS

Rabbits weighing about 2 kg were used The left hind leg was immobilized in one of the following ways resection of one centimetre of the calcaneus tendon resection of the sciatic nerve or fixation of the leg in plaster of Paris with the knee joint in the flexed position and the ankle joint in the intermediate position After periods of immobilization varying from 4 days to 4 weeks the animals were anaesthetized with Nembutal® and heparinized They were then connected via a tracheotomy to a respirator and breathed atmospheric air The common carotid artery was prepared free and a catheter was introduced through which arterial blood was obtained Holes were drilled with a dentist s drill through the corticalis into the marrow cavity at exactly the same points distally of the front sides of both tibiae Heparinized capillary tubes were used for sampling they held about 50 microliters and were introduced into the marrow cavity through the holes The blood in the first tube was discarded on account of its content of fat and cells from the bone marrow From each tibia and from the art carotis three or four capillary tubes full of blood were taken

Astrup s technique was used in analysing the blood samples It permits the determination of the actual pH and after equilibration with known CO mixtures of the actual pCO and the standard bicarbonate in small volumes of blood (Siggaard Andersen et al 1960 Siggaard Andersen 1962)

## RESULTS

The results reported here refer to our preliminary experiments and the investigation is being continued by one of us (Semb) for the purpose of obtaining more information about the blood changes found

The actual pH was obtained in all the experimental animals though at the beginning of the series of experiments the blood samples were not always equilibrated As regards the actual pH in the blood from each leg the results are best shown in the diagram in Figure 1 which illustrates the pH differences in blood from immobilized and free tibiae after the tibia had been immobilized for different periods The pH in the control tibia was made equal to 0 The diagram shows a clear tendency to higher pH values in intramedullary blood from the immobilized tibia for periods of immobilization longer than 10 days The standard bicarbonate values in blood from the right and left tibiae showed no certain variations The differences in pH were due to the fact that the pCO was lower on the immobilized side See the diagram in Figure 2 which shows the relations between the actual pH and the pCO in blood from immobilized and free tibiae

In four cases the right sciatic nerve was prepared free on a level with the hip joint (after the above-mentioned analyses had been performed) and the nerve was subjected to Faradic stimulation for 2

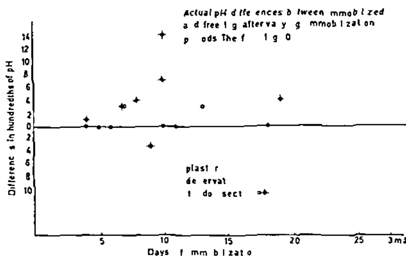



*Figure 1*

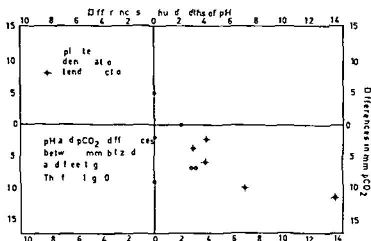



*Figure 2*

minutes A tonic cramp arose in the musculature of the extremity Immediately after this cramp fresh blood samples were taken from the marrow cavity of the right tibia Owing to the muscular cramp there was a displacement of the standard buffer line to the left on account of a reduced standard bicarbonate indicating a metabolic acidosis In a couple of cases there arose a general metabolic acidosis which could be observed in the arterial blood as well

## DISCUSSION

This investigation has shown that when an extremity is immobilized there will be increased alkalinity in the *intramedullary blood*. The rise in pH is connected with the lower carbon dioxide tension in the same blood. This change in the acid-base status of the blood cannot be explained in specific terms, but some views may be quoted. Owing to the fact that the musculature on the immobilized side is inactive, its blood flow is reduced to a minimum. For this reason it is possible that relatively more arterial blood is shunted through the bone. A more rapid flow results in a more rapid removal of carbon dioxide and less use of the oxygen in the blood. In order to shed more light on these problems the $O_2$ saturation of the blood should also be determined, and an investigation of this kind has been commenced by one of us (Semb).

However, the investigations reported in the introduction argue against less use of the blood; they showed that in immobilization osteopenia there seems to be normal formation of bone in combination with increased resorption. Both new formation and resorption imply high metabolic activity.

The pH observed in the marrow cavity, however, is not necessarily equivalent to the pH at the site of the metabolically active processes in the actual bone tissue. Large pH gradients may exist. However, it is interesting to note that the pH is so much higher in the marrow cavity with mobilization, as one might have expected that it would have been normal or even lower than normal owing to the addition of acid venous blood from resorption foci in the bone tissue.

The experiments have yielded results which cannot yet be completely explained, but at any rate they have not confirmed the theory that *the bone resorption in inactivity osteoporosis is caused by local acidosis in the bone tissue*. The experiments primarily involve a new approach to the investigation of the pathophysiology of bone tissue.


## SUMMARY

The pH and $pCO_2$ of intramedullary blood from the tibiae of rabbits were investigated by Astrup's micro method. One of the hind legs of each rabbit was immobilized in different ways (nerve resection, tendon resection and fixation in plaster of Paris). It was then possible to observe that immobilization leads to increasing alkalinity *of the blood in the tibia on the immobilized side*, owing to a lower $pCO_2$. The results are discussed.

## RESUME

Le pH et le pCO du sang intramedullaire du tibia de lapin a ete examine par la micro methode d Astrup Une des pattes arriere de chaque lapin a eté immobilisee de differentes manieres (resection de nerf resection de tendon et fixation dans la platre de Paris) Il a éte alors possible d observer que l immobilisation conduit a une alcalinite accrue du sang dans le tibia du cote immobilise due a un pCO plus bas Discussion des resultats

## ZUSAMMENFASSUNG

Der pH und pCO intramedullären Blut der Tibia von Kaninchen wurde mittels Astrups Mikromethode untersucht Einer der Hinterfusse jedes Kaninchens wurde in verschiedener Weise ruhiggestellt (Nervresektion Sehnenresektion und Gipsverband) Es war dann möglich zu beobachten dass Ruhigstellung zu einer erhohten Alkalinitet des Blutes in der Tibia auf der ruhiggestellten Seite wegen eines herabgestzten pCO fuhrte Die Ergebnisse werden besprochen



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# AGE AND SEX RELATED CHANGES IN THE AMOUNT OF CORTEX OF NORMAL HUMAN RIBS[1]

*By*

HIDEAKI TAKAHASHI[2] and HAROLD M. FROST[3]

Received 10.iv.65

The group of diseases designated by the term the osteoporoses is becoming increasingly important as the average age of our population rises. Present methods of treating these diseases leave much to be desired since it is only rarely possible to demonstrate an increase in bone mass even after years of faithful adherence to one of the commonly used therapeutic regimes. As *Sedlin* noted (1961a, 1964b) this failure of treatment has suggested to many that our present concepts of the physiologic mechanisms causing osteoporosis may benefit from reexamination. In this respect it is axiomatic that it is difficult to understand diseased tissues unless one has a good knowledge of the normal.

These facts have stimulated a number of investigators to perform longitudinal studies (with respect to age) of normal bone hoping thereby to learn how to define what the normal is and to provide a rational basis for comparing abnormal skeletal tissue with normal. These studies include the ash and volumetric studies of *Trotter, Broman & Peterson* (1960) and of *Merz, Trotter & Peterson* (1956), the physical densities of *Wray, Sugarman & Schneider* (1963), the roentgen densities of *Lindahl & Lindgren* (1962), the highly accurate densities of *Arnold* (1960), and the osteoid seam counts of *Jee et al.* (1964). Almost all authors who have worked on these problems have

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tried to devise or/and refine some basis for quantitative and accurate measurement or one or more properties of bone

This study was influenced by the following truism In a very general frame of reference and in adults bone may be gained or lost at one or any combination of four locations the periosteal surfaces the surfaces of the vascular channels within cortical bone the cortical endosteal surface and the trabecular endosteal surface In defining normal it seems reasonable to measure the age related changes at these surfaces and then to compare diseased skeletons with these data The precise definition of the so called "physiologic age related changes in quantity density and composition *within* cortical bone at a standard sampling site has been undertaken by others (*B N Epker & H M Frost* in Detroit W *S S Jee* in Salt City and *J S Arnold* in San Diego) as has the measurement of trabecular bone changes with age (by W *S Jee & coworkers* in Salt City and *J S Arnold & R Murray* in San Diego) In this article we report a study of the age associated changes in the transverse sizes of the periosteal and endosteal envelopes of standard rib samples taken from metabolically normal people of all ages supplementing thereby earlier reports by *Sedlin* (1964a) *Sedlin et al* (1963) and *Epker & Frost* (1964)

## MATERIALS AND METHODS

### *Materials*

The mid diaphysis of the 5th 6th or 7th rib from 3 6 cases (117 females and 209 males) was available for this study through systematic sampling extending over an 8 year period Ages ranged from one week to 90 years and the age distribution is shown in Tables 1 and 2 Approximately one quarter of the ribs were obtained from the operating theatre where thoracotomy was performed Indication for the thoracotomies included repairs of lesions such as coarctation of the aorta hiatus hernia e ophageal diverticulum and trauma and biops of the lung or the media tinum for previously undiagno ed but nondebilitating solid lesions The remaining cases were collected from the medical examiner s office and a general hospital autop y room Causes of de th in this group included automobile accidents homi cides suicides va cular incident unknown cause and asphyxiation These subjects ere thought to be healthy were functioning normally and were not receivin medical attention until their unexpected death Generalized serious metabolic diseases were believed to be ab ent in these people on the basis of both the clinical history and the finding of the autopsies No cases which were diagnosed during life as having osteoporo is or other metab lic bone disease were included in this series and no cases were accepted if their records were inadequate to substantiate the e matters We are greatl indebted to the generosity of Drs F S Zawadski R H H rn and ( Fine for this material and for access to all rele ant records

*Table 1 209 Male Ribs Cross Section Area Measurements*

| Age range | Mean Age | Number of Subjects | Cortical Area (S E ) | Marrow Area (S E ) | Total Area (S E ) |
|---|---|---|---|---|---|
| 0-4 | 1 2 | 19 | 11 6 (0 9) | 6 7 ( 8) | 18 3 (1.5) |
| 0-10 | 2 9 | 2[illegible] | 13 6 (1 1) | 8 9 (2 5) | 22 4 (2.3) |
| 11-20 | 15 3 | 14 | 26 6 (1 5) | 26 7 (3 1) | 55 0 (3 1) |
| 21-30 | 24 5 | 2[illegible] | 26 3 (1 8) | 36 1 (1 3) | 6[illegible] 2 (1 7) |
| 31-40 | 3[illegible] 7 | 29 | 22 5 (2 0) | 43 4 (1 6) | 66 1 ([illegible] 4) |
| 41-50 | 44 2 | 31 | 21 7 (3 2) | 40 3 (1 9) | 6[illegible] 5 (3 5) |
| 51-60 | 54 5 | 33 | 21 7 (0 9) | 40 9 (1 1) | 6[illegible] 0 (0 9) |
| 61-70 | 64 3 | 23 | 19 3 (1 [illegible]) | 44 5 ([illegible] 1) | [illegible]4 0 ([illegible].2) |
| 71 + | 73 8 | 23 | [illegible]0 1 (1.2) | 53 7 (1 8) | 73 7 (2 6) |

*Table 2 117 Female Ribs Cross Section Area Measurements*

| Age range | Mean Age | Number of Subjects | Cortical Area (S E ) | Marrow Area (S E ) | Total Area (S E ) |
|---|---|---|---|---|---|
| 0 4 | 1 3 | 14 | 10 0 (1 6) | 6 2 (2 1) | 1[illegible] 3 ([illegible] 8) |
| 0-10 | 2 8 | 18 | 11 8 (2 6) | 7 6 (1 7) | 1[illegible] 2 (3 0) |
| 11-20 | 17 | 6 | 2[illegible] 3 (2 9) | 15 8 (2 3) | 3[illegible] 1 (3 4) |
| 21-30 | [illegible] 0 | 20 | 20 0 (1 7) | 21 1 (1 4) | 41 5 ([illegible] 5) |
| 31-40 | 34 0 | 23 | 19 5 (2 2) | 21 1 (1 9) | 40 8 ([illegible] 5) |
| 41-50 | 44 1 | [illegible] | 19 6 ( 8) | 23 3 (1 5) | 4[illegible] 9 (1 7) |
| 51 + | 58 9 | 30 | 1[illegible] 1 (1 8) | 26 7 (1 4) | 4[illegible] 9 ([illegible] 1) |
| 61 + | 71 | 14 | 17 9 (3 0) | 33 9 (2 6) | 5[illegible] 6 ([illegible] 9) |

(S E ) The standard error of the mean

## METHODS

*Sections*

Fresh mineralized cross sections averaging 50 70 micra in thickness were made by hand grinding of the ribs that were examined (*Frost* 1958) The sections were cut *within 5 degrees of perpendicularity to the longitudinal axis of the rib* They were stained 48 hours with a 50 per cent ethanolic 1 per cent basic fuchsin stain air dried and mounted in resin There were three complete cross sections per case and a total of 978

*Measurements of Cortical and Total Cross sectional Area*

A point count method employing a calibrated grid and described elsewhere (*Sedlin Frost & Villanueva* 1963) was used to measure the areas of the cortex and of the marrow space as observed in the complete cross section (*See Figure 1*) The results are shown in mm Each area in each section was measured with a precision of ± 8 mm Values for each of the three cross sections per case were thus obtained

and the mean for each case calculated. The cases were arrayed in 10 year age groups and means for each group were calculated.

*Figures of Merit*

The C/T ratio of each group was obtained as described by *Sedlin* (1964 a) by division of the cortical area ($A_c$) by the total area ($A_t$). This may be written

$$C/T = \frac{A_c}{A_t} \quad (1)$$

This number is the decimal part of the volume of the periosteal envelope that is filled with cortical bone.

The parabolic index of each group was also calculated. It has an optimum numerical value of 0.25 (*Epker & Frost* 1964) which is obtained by substituting in this formula

$$Y = X\,(1 - X) \quad (2)$$

where Y is the parabolic index, X is the cortical area expressed as a decimal fraction of the total area, and unity represents the normalized total area. In terms of the parameters which were actually measured this equation can be written where $A_m$ is the marrow cross section area

$$Y = \frac{A_c \times A_m}{(A_t)} \quad (3)$$

This number (i.e. Y) indicates the relative resistance of a rib to buckling when under longitudinal compression, and the farther below 0.25 the number is, the weaker is the bone.

## RESULTS

The cortical, marrow and total cross section areas are summarized in Table 1 for men and 2 for women. The figures of merit are shown in Table 3.

The amount of cortical bone in ribs is definitely different between male and female, women having less. This difference is highly significant ($p < .001$) as was also found by *Sedlin et al.* (1963). The maximum amount of cortical bone occurs between ages 15 and 25 in both sexes and declines afterwards. The decline by age 60 is about 25 per cent of the value at age 20. It is again demonstrated that the ratio of the cortical to the total cross section constantly decreases throughout life in both sexes. Women consistently show a larger ratio than men with the exceptions of the youngest and oldest groups. After skeletal maturity the parabolic index of the male ribs shows a steady decrease but that of the females tends to stay near the maximum level up until age 60, when it begins to decrease rapidly.

*Table 3 Figures of Merit 326 Human Ribs*

| Age range | $A_c/A_t$ ratio | | Parabolic Index | | Mean Age | |
|---|---|---|---|---|---|---|
| | Male | Female | Male | Female | Male | Female |
| 0–4 | 0.633 | 0.615 | 0.232 | 0.237 | 1.2 | 1.3 |
| 5–9 | 0.594 | 0.609 | 0.241 | 0.238 | 6.9 | 7.9 |
| 10–14 | 0.489 | – | 0.250 | – | 12.8 | – |
| 15–19 | 0.482 | 0.584 | 0.250 | 0.243 | 16.8 | 17.2 |
| 20–24 | 0.413 | 0.512 | 0.242 | 0.249 | 21.9 | 22.5 |
| 25–29 | 0.435 | 0.463 | 0.246 | 0.249 | 27.0 | 28.1 |
| 30–34 | 0.349 | 0.506 | 0.227 | 0.250 | 31.0 | 31.3 |
| 35–39 | 0.338 | 0.446 | 0.224 | 0.247 | 37.4 | 37.0 |
| 40–44 | 0.355 | 0.444 | 0.229 | 0.247 | 41.8 | 42.1 |
| 45–49 | 0.339 | 0.470 | 0.224 | 0.249 | 47.0 | 47.0 |
| 50–54 | 0.338 | 0.438 | 0.224 | 0.246 | 51.5 | 52.9 |
| 55–59 | 0.311 | 0.411 | 0.214 | 0.242 | 56.8 | 57.3 |
| 60–64 | 0.321 | 0.430 | 0.218 | 0.245 | 61.4 | 62.0 |
| 65–69 | 0.283 | 0.360 | 0.203 | 0.230 | 67.3 | 66.8 |
| 70 + | 0.272 | 0.267 | 0.198 | 0.196 | 73.8 | 79.8 |

Cortical area/total area ratio

## DISCUSSION

1 *The Menopause* The changes in total and cortical cross section areas do not correlate with the onset of either puberty or the menopause[1] This is interesting since it has been widely believed (i e *Albright & Reifenstein* 1948 *Snapper* 1957) that ovarian function bears some causal relationship to postmenopausal osteoporosis

A similar lack of evidence for a change in amount of bone especially at menopause has been found by others (for example *Lindahl & Lindgren* 1962 *Meema et al* 1966 *Trotter et al* 1960) These facts suggest that (i) in healthy women there is no increase in the rate of loss of bone at or immediately following cessation of cyclic ovarian function and (ii) if the menopause is causally related to postmenopausal osteoporosis it may be through an extraovarian mechanism It does not seem likely that ribs provide a false picture of the age related changes in the skeleton in general because it has been shown that ribs do reflect the general trends throughout the skeleton and in fact do so sooner than most other bones For example this is shown by an elegant study done by *Amprino & Marotti* (1964) and was noted also by *Johnson* (1964a 1964b)

1 Unless otherwise noted the .05 level was tested for significance

2 *The Total Cross Section Area* There is a significant increase in the total cross sectional areas of both male and female ribs after age 60 This increase is proportionately larger in women than men When it is realized that the 65 and 70 year old patients in this study grew up in a public health and nutritional environment that was more than 35 years behind that of the subjects aged 20–35 and were therefore of generally smaller stature it can be seen that one would have been led to predict as more likely *a smaller* total area in the older groups rather than a larger one This kind of age related increase in size of a bone was first reported by *Sedlin et al* (1963) on the basis of fewer rib samples than are reported here Since then *Smith & Walker* (1964) have reported a highly significant age related increase in the transverse diameters of femurs in more than 2000 women The increase approximated 5 per cent between ages 40 and 80 These findings suggest that periosteal new bone apposition does not stop at skeletal maturity but rather subsides to some basal level

One meaning of the age associated changes in total area in both men and women is that the periosteal surfaces of ribs are *never in negative balance* during life That is in sum they never lose bone so the volume of space inside the periosteum never shrinks

3 *The Cortical Area* In both men and women the amount of cortical bone peaks at age 15–30 and thereafter declines The loss is on the order of 25–30 per cent for both sexes This parallels previous similar findings by many for example *Trotter Broman & Peterson* (1960) *Lindahl & Lindgren* (1962) It appears that the aging process normally carries with it an associated loss of skeletal material which has been called the physiologic osteoporosis

4 *The Marrow Area* The cross section area of the marrow cavity continually enlarges during life the rate of enlargement leveling off temporarily during the age span 20–40 years The shape of this curve is similar in both men and women Since the cortical areas decline after age 30 while the total areas increase the enlargement of the marrow cavity must be the direct cause of the decrease in cortical area and it must be larger than the increase in the total area It follows that after age 30 the cortices of these ribs should become thinner and this is the case

One meaning of the changes in marrow area is that when regarded as a whole *the endosteal surface of the cortex is never in positive*

*balance*. In other words the marrow cavity *never normally shrinks in size*. This suggests that in osteoporosis this negative endosteal balance probably is the mechanism directly responsible for the associated *cortical thinning*.

5. *The C/T Ratio*. *Sedlin* (1964a) reported a study of the age associated changes in the proportion of the periosteal envelope that is filled with bone in ribs. His findings are essentially confirmed in this study which contains well over twice as many subjects as his. This study does show that there is more tendency to retain bone in aging women than in men until age 50. Thereafter women lose bone quickly, especially when compared to men. It has been stated, on the basis of histological findings, that estrogen suppresses both bone resorption and formation (*Frost* 1963). If this were true, one could predict that women would *retain bone better than men before the menopause and lose it faster* afterwards. It is important that this change, which does correlate with the menopause, is the result of a change in the proportions of bone resorption and formation at two surfaces, periosteal and cortical endosteal. The changes at either surface alone fail to show statistically significant menopause associated change.

6. *The Parabolic Index*. In mechanics this relationship (which is usually given in different but equivalent form) is known as the *parabolic index for nominally concentrically loaded columns* (*Popov* 1962). The closer the figure of merit approaches to the ideal value of 0.25 the more efficiently is the available structural material being used to withstand longitudinal compression loads. While the figure of merit may assume any lesser value than 0.25 it cannot exceed this number.

Again a significant difference emerges between men and women. The men's index falls off steadily after age 35 while the women's remains high until age 50, after which it then shows a rapid decline. Values at the end of the life span are similar in both groups. Again this parameter seems to show a change associated with the menopause. This would be expected because of the similar finding concerning the C/T ratio and because of the close mathematical relationship between these two figures of merit.

SUMMARY

Cross section areas were measured on the middle third of the 5th, 6th or 7th rib from 326 metabolically normal people. In this sample the

amount of bone in the cortex peaks between ages 15–25 in both sexes and thereafter declines reaching values 25 per cent less by age 65. The space inside the periosteal envelope increases during childhood, levels off at age 20, and begins to increase again after age 55. The periosteal bone surface seemed never to be in net negative balance (between resorptive and formative activity), while the cortical endosteal surface seemed never to be in a positive one. The observed changes did not associate clearly with puberty or the menopause.

## RESUME

Des sections transversales ont ete mesurees dans le tiers du milieu des 5eme, 6eme et 7eme cotes chez 326 sujets normaux metaboliquement. Dans ces echantillons la quantite d'os dans le tissu compact culmine entre l'age de 15 et 25 ans chez les deux sexes pour decliner ensuite en atteignant des valeurs inferieures de 25 pour cent a l'age de 65 ans. L'espace a l'interieur du perioste augmente durant l'enfance, atteint son niveau a 20 ans et recommence a augmenter apres 55 ans. La surface du peroste ne semble jamais avoir un equilibre negatif (entre la resorption et l'activite de formation) tandis que la surface corticale endostale ne semble jamais avoir un équilibre positif. Les modifications constatees ne sont pas clairement liees a la puberte ou a la menopause.

## ZUSAMMENFASSUNG

Querschnittsschnitte im mittleren Drittel der 5., 6. oder 7. Rippe von 326 Personen mit normalem Grundumsatz wurden gemessen. In diesen Präparaten erreichte die Knochenmenge in der Cortex die hochsten Werte zwischen 15–25 Jahren bei beiden Geschlechtern und sinkt hernach, indem sie im Alter von 65 Jahren Werte erreicht, die 25 pro Zent niedriger liegen. Der Raum innerhalb der periostalen Hulle nimmt während der Kindheit zu, halt sich unverandert von 20 Jahren ab und beginnt nach dem Alter von 55 Jahren wieder zuzunehmen. Die periostalen Knochenoberflächen scheinen sich niemals in einer negativen Balanz (zwischen resorbierender und aufbauender Tätigkeit) zu befinden, während die kortikale endostale Oberfläche niemals eine positive aufzuweisen scheint. Die beobachteten Veränderungen standen nicht in deutlicher Verbindung mit der Pubertät oder der Menopause.

*balance.* In other words, the marrow cavity never normally shrinks in size. This suggests that in osteoporosis this negative endosteal balance probably is the mechanism directly responsible for the associated cortical thinning.

5. *The C/T Ratio.* *Sedlin* (1964a) reported a study of the age-associated changes in the proportion of the periosteal envelope that is filled with bone in ribs. His findings are essentially confirmed in this study, which contains well over twice as many subjects as his. This study does show that there is more tendency to retain bone in aging women than in men until age 50. Thereafter women lose bone quickly, especially when compared to men. It has been stated, on the basis of histological findings, that estrogen suppresses both bone resorption and formation (*Frost* 1963). If this were true, one could predict that women would retain bone better than men before the menopause, and lose it faster afterwards. It is important that this change, which does correlate with the menopause, *is the result of a change in the proportions of bone* resorption and formation at two surfaces, periosteal and cortical endosteal. The changes at either surface alone fail to show statistically significant menopause-associated change.

6. *The Parabolic Index.* In mechanics this relationship (which is usually given in different but equivalent form) is known as the *parabolic index for nominally concentrically loaded columns* (*Popov* 1962). The closer the figure of merit approaches to the ideal value of 0.25, the more efficiently is the available structural material being used to withstand longitudinal compression loads. While the figure of merit may assume any lesser value than 0.25, it cannot exceed this number.

Again a significant difference emerges between men and women. The men's index falls off steadily after age 35, while the women's remains high until age 50, after which it then shows a rapid decline. Values at the end of the life span are similar in both groups. Again this parameter seems to show a change associated with the menopause. This would be expected because of the similar finding concerning the C/T ratio, and because of the close mathematical relationship between these two figures of merit.

SUMMARY

Cross section areas were measured on the middle third of the 5th, 6th or 7th rib from 326 metabolically normal people. *In this sample* the

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# THE BREAKING STRENGTH OF NORMAL AND IMMOBILIZED CORTICAL BONE FROM DOGS

By

HELGE SEMB

Received 19 II 66

Osteoporosis is defined as a condition with a reduced amount of bone compared to normal There are only few reports in the earlier literature on investigations of physical properties of bone from osteoporotic subjects and published results are a little divergent (*Allison & Brooks* 1921 *Gillespie* 1954 *Vose Stover & Mack* 1961) The data on physical properties of bone from osteoporotic subjects obtained up to the present are in most cases established on investigations of whole bones (*Allison & Brooks* 1921 *Gillespie* 1954)

*Allison & Brooks* (1921) immobilized one fore leg of dogs in different ways and were able to demonstrate an osteoporosis in the non used bones The authors found that the breaking strength was decreased in immobilized whole bones but normal when related to the cross section area of the bones *Gillespie* (1954) caused disuse osteoporosis in kittens by cutting the lumbar ventral nerve roots and in hind limbs of rats by denervation When testing the physical properties of whole osteoporotic bones from kittens normal values for the breaking stress and modulus of elasticity were found The breaking stress was decreased in immobilized rat bones but the modulus of elasticity was normal

In the last decade however new methods have been developed for investigations of the physical properties in smaller more homogenous bone specimens (see *inter alia Evans* 1957) *Sedlin* (1965) has performed a comprehensive investigation of the physical properties of standardized specimens from human femurs under differing external circumstances in conjunction with storing preparing and testing bone specimens of different shapes and sizes

In conjunction with other investigations of different parameters of non used bones the present author considered it to be of interest to include an investigation of the breaking strength of such bone tissue especially as earlier investigations of the physical properties of osteoporotic bone have given somewhat varying results

## MATERIAL AND METHODS

Twelve adult mongrel dogs were used In 9 cases one fore leg was immobilized with plaster casts In 3 dogs one fore leg was paralyzed by brachial plexus resection The immobilization periods varied between 4 and 112 days (Table 1) The dogs received ordinary dog food during the investigation periods and could move about freely partly in ordinary cages and partly outdoors twice daily They moved supported only on the three unaffected legs

After different immobilization periods the animals were killed with an overdose of pentobarbital sodium (Nembutal) Material for testing of physical properties was taken from the distal part of both radial bones and the bone pieces were put in plastic bags and in a refrigerator (−20 C) in a fresh state and kept in this condition prior to preparation and measuring It was shown by *Sedlin* (1965) that storing of cortical bone at −20 C does not affect its physical properties

*Table 1*

| Animal No | Type of immobilization<br>P = plaster<br>D = denervation | Duration of immobilization (Days) |
|---|---|---|
| 1 | P | 4 |
| 2 | D | 4 |
| 3 | P | 10 |
| 4 | D | 10 |
| 5 | D | 20 |
| 6 | P | 21 |
| 7 | D | 28 |
| 8 | P | 29 |
| 9 | P | [illegible] |
| 10 | P | 49 |
| 11 | P | 59 |
| 12 | P | 112 |

*Preparation of specimen* One 5 cm long piece of both radial bones was removed proximally to a level two cm from the radiocarpal joint These bone pieces were divided longitudinally with a handsaw in 6 separate samples from different sectors of the bone cross section in accordance with Figure 1 The further shaping of the specimens was done by manual grinding using special shaping tools described by

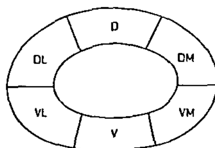



*Figure 1 Outline of a cross section from the sampling region showing the distribution of the different samples (D dorsal DM dorsal medial DL dorsal lateral V volar VM volar medial VL volar lateral)*

*Sedlin & Hirsch* (1966) During all preparation the samples were continuall cooled with water

After the final shaping of the specimens their breadth and thickness at the mid point were measured by a friction release micrometer accurate to 0 005 mm Each specimen had the approximate size 50 × 2 × 1 mm Except at shaping and measuring the specimens were stored at —20 C in Ringer s solution

*Method of testing* Before the tests the specimens were brought to room temperature in their containers and maintained at room temperature for about one hour The tests were performed in a room with controlled temperature (21 C ± 1 ) and humidit (66 per cent ± 2 per cent) All specimens were placed in Ringer s solution of room temperature during the tests according to the method used by *Sedlin & Hirsch* (1966) and *Sedlin* (1965)

All tests were performed with the same equipment (An Instron TT CM tensile test machine with clasimeter head) The specimens were placed on supports and loaded as simple beams with a progressive central load to failure The rate of deformation was 1 cm/min and the distance between supports was 15 mm 4 5 × 9 81 N full scale load was chosen and the results were recorded at a recorder speed of 50 cm min The data were then obtained from the recordings

The modulus of elasticity was calculated from the formula $\sigma = \frac{3\,PL \times 9.81}{BD}$ N mm

The modulus of ela ticity was calculated from the formula $F = \frac{PL^3 \times 9.81}{3Iy}$ N mm

(*Roark* 1954) Energ absorbed to failure was determ ned util zing the area under the load-deformation diagram and a constant speed calculated from data from load peed and the specimen size The area under the curve was measured with a plani meter (less than 1 per cent error)

| | |
|---|---|
| $\sigma$ — Stress | L — Span length of specimen |
| P — Load | B — Breadth of specimen |
| I — Moment of inertia | D — Depth of specimen |
| F — Modulus of elasticity | y — Deflection in bending. |

In this work kp has been converted to N (Newton) the new international measuring standard.

## RESULTS

In Table 2 the results are presented as mean differences of some physical properties of untreated and immobilized bone samples Samples from one region of all the untreated radial bones were matched against samples from the corresponding region of all immobilized bones In calculating the mean differences the different immobilization times in the animals were not taken into consideration

*Table 2 The differences in some bending properties of untreated and immobilized cortical bone from different regions of the dog radius The values are mean differences ± standard error of the mean*

| Site of specimen† | Mean differences control – immobilized bone | | |
|---|---|---|---|
| | Ultimate fiber stress N/mm² | Modulus of elasticity N/mm² × 10² | Energy absorbed to failure Nm/mm³ × 10⁴ |
| D | 3 6 ± 10 6 | −6 0 ± 9 1 | 1 5 ± 25 0 |
| DL | 0 0 ± 8 7 | −7 1 ± 7 6 | −0 4 ± 17 7 |
| DM | −7 2 ± 7 9 | −9 9 ± 6 5 | 8 0 ± 17 7 |
| V | 11 2 ± 7 3 | −0 8 ± 6 7 | 23 1 ± 19 7 |
| VL | 19 7 ± 14 2 | −4 7 ± 12 9 | 13 9 ± 17 8 |
| VM | 0 1 ± 7 8 | −0 1 ± 8 0 | 14 3 ± 20 9 |
| No of samples | 12 | 12 | 12 |

The values are given in accordance with the new international system of measures (S.I) N = newton Nm = newton meter

† D dorsal DL dorsal lateral DM dorsal medial V volar VL volar lateral VM volar medial

In no sample region was there any significant mean difference of the physical properties tested in untreated and immobilized bones Nor were there any definite trends to differences of physical properties in treated and untreated samples according to the length of the immobilization periods

Microradiographs from the ends of the sample region showed evident signs of osteoporosis consisting of increased numbers of resorbtion cavities and/or reduced volume of trabecular bone when the immobilization periods were at least 3 weeks (Figure 2)

*In Table 3 some physical properties of untreated* cortical bone from different regions of dog radius are shown The ultimate fiber stress

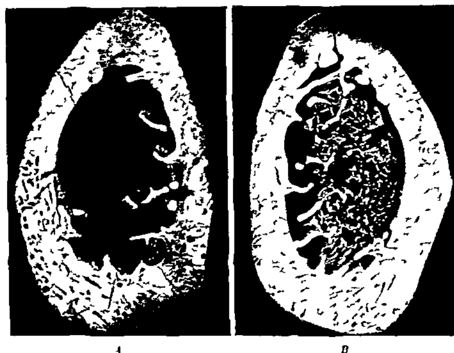



*Figure 2 Microradiographs of cross sections (100 microns) taken from the distal ends of the radial bone samples from a dog with one fore limb immobilized in plaster cast for seven weeks Note the reduced amount of bone trabeculae the cortical thinning and the increased numbers of resorbtion cavities in the immobilized (A) bone compared with the the control (B) bone*

*Table 3 Some bending properties in different regions of untreated cortical bone from dog radius Mean values ± standard error of the mean*

| Site of specimen | Ultimate fiber stress $N/mm^2 \times 10$ | Modulus of elasticity $N/mm^2 \times 10^3$ | Energy absorbed to failure $Nm/mm^3$ |
|---|---|---|---|
| D | 22.3 ± 0.9 | 15.2 ± 0.8 | 2.68 ± 0.16 |
| DL | 22.7 ± 0.5 | 15.5 ± 0.5 | 3.09 ± 0.23 |
| DM | 21.1 ± 0.7 | 14.6 ± 0.5 | 2.49 ± 0.12 |
| V | 22.6 ± 0.9 | 15.5 ± 0.6 | 2.81 ± 0.21 |
| VL | 23.1 ± 1.2 | 15.6 ± 0.9 | 2.75 ± 0.13 |
| VM | 24.1 ± 1.0 | 17.0 ± 0.7 | 2.62 ± 0.17 |
| No of samples | 12 | 12 | 12 |

For nomenclature and symbols see Table 2

was significantly higher in cortical bone situated volar medial than in dorsal medial bone (24.1 ± 1.0 and 21.1 ± 0.7 N/mm × 10³ respectively). The *modulus of elasticity was significantly higher* in volar medial cortical bone than in dorsal lateral and dorsal medial bone (17.0 ± 0.7, 15.5 ± 0.5 and 14.6 ± 0.5 N/mm × 10³ respectively). Concerning the energy absorbed to failure there were no significant differences between samples from different regions.

## DISCUSSION

In the actual investigation the bone samples tested were of cortical origin. There were no significant mean differences of the breaking strength in control and immobilized bone. Thus it is evident that the increased porosity noted in most of the immobilized cortical bone samples did not affect the physical properties to such an extent as to be revealed by the methods used. This fact is in agreement with earlier findings. Thus *Maj* (1938) found no correlation between the microanatomy and bending strength when the Haversian canal volume was less than 50 per cent. No significant correlation between ultimate yield loading and the size and frequency of Haversian canals was noticed by *Vose* (1962). Nor could *Sedlin & Hirsch* (1966) and *Sedlin* (1965) find any correlation between the Haversian canal volume and individual values for ultimate fiber stress and energy absorbed to failure. Only a weak nonsignificant correlation was noticed between porosity and the modulus of elasticity. However *Evans* (1958) found that the ultimate tensile strength was lower in bone with an increased number of small osteones than in bone with a few large osteones, but he also noticed that specimens with fewer osteones occasionally were weaker than specimens with more osteones although their origin was the same bone. Also *Currey* (1959) demonstrated a negative correlation between the ultimate tensile strength and the number of Haversian system. He explained his results by the large canals in young Haversian systems which reduced the breaking area and by the lower mineral contents in growing Haversian systems.

The increased fragility of osteoporotic bone causing above all femoral neck, rib and vertebral fractures involves all of the bone including cancellous and cortical bone. The first roentgenological signs of osteoporosis in a tubular bone are usually noticed in the metaphyseal regions where both cortical thinning and increased translucency of cancellous bone can be seen. This fact is in agreement with the find

ings of Vose et al (1961) These authors demonstrated lower breaking stresses in 5 out of 6 intact femurs from osteoporotic subjects and lower breaking loads in all 6 osteoporotic femurs tested They also noticed that osteoporotic femurs had a tendency to fracture near the distal end when centrally loaded while normal femurs ordinarily fractured at the middle of the shaft at the point of loading Their results thus indicate a lower resistence to loading in the distal metaphysis where both cortical and cancellous bone are greatly reduced in osteoporosis However the same authors also demonstrated that the breaking strength of machined samples from osteoporotic femurs was 30 per cent higher than that of samples from normal femurs Their findings thus indicate higher intrinsic breaking strength in femoral bone from osteoporotic subjects than in normal femoral cortex but lower breaking strength of osteoporotic whole femurs They also demonstrated a higher degree of mineralization in osteoporotic cortical bone than in normal bone They ascribed the higher intrinsic strength to the increased degree of mineralization It was concluded that the loss of bone substance was responsible for the increased fragility The results of the present investigation support this conclusion as there was no significant decrease in the intrinsic breaking strength in immobilized cortical bone although in bones immobilized for at least 3 weeks there were evident signs of osteoporosis *Allison & Brooks* (1921) also postulated that decreased breaking strength of immobilized bones is caused by diminution in the thickness of the bone rather than by any changes in the nature of the bone substance

It might seem illogical to present the results as mean values of data from all animals independent of the length of immobilization as definite microradiographic signs of osteoporosis were noticed only after three weeks immobilization However the aim of the investigation was to detect any intrinsic changes in the physical properties of the non used bone substance Other qualitative changes consisting of decreased phosphorus uptake in certain microscopic cortical bone structures from immobilized metacarpal dog bones have been found by the author after an immobilization in plaster cast or by denervation for only four days (*Semb* 1966) That is why the results are given as mean values from all animals used in the investigation

There were some differences in ultimate fiber stress and modulus of elasticity in cortical bone samples from different areas of untreated cortical bones from the radius The samples from the volar medial sector had the greatest strength in bending Regional differences in

physical properties of one bone have earlier been demonstrated by *inter alia Evans & Lebow* (1951), *Sedlin & Hirsch* (1966) and *Sedlin* (1965).


## SUMMARY

One fore leg of twelve dogs was immobilized with plaster cast or by denervation for periods varying from 4 to 112 days. Standard specimens were prepared from different sectors of the distal part of immobilized and untreated radial bones.

Using a tensile test machine the specimens were centrally loaded to failure as supported unfixed beams. There was no significant difference between the ultimate fiber stress, the modulus of elasticity and the energy absorbed to failure in samples from untreated and immobilized bones. The results indicate that the intrinsic strength of osteoporotic cortical bone is normal. The increased fragility of osteoporotic bone must be due to the reduced bone volume.

Untreated cortical bone from the volar medial sector of the distal part of the radius showed increased ultimate fiber stress and modulus of elasticity.



## RESUME

Une patte avant shez douze chiens a éte immobilisee dans le platre ou par denervation pour des periodes variant entre 4 et 112 jours. Des specimens standard ont ete prepares de differents secteurs de la partie distale de l'os immobilise et d'os radial non traite.

Utilisant une machine de testage de la tension, les specimens ont été charges centralement jusqu'a rupture comme des poutres supportées non fixees. Il n'y avait pas de difference sensible entre la tension finale de la fibre, le module de l'elasticite et l'energie absorbée jusqu'a rupture dans les echantillons d'os non traites et immobilises. Les resultats indiquent que la force intrinseque de l'os cortical osteoporosique est normal. La fragilite accrue de l'os osteoporosique doit etre due au volume reduit de l'os.

L'os cortical non traite du secteur anterieur median de la partie distale du radius montre une augmentation de la tension finale de la fibre et du module d'élasticite.

## ZUSAMMENFASSUNG

Im Vorfuss von zwölf Hunden wurde mittels Gipsverband oder Denervation für eine Zeitspanne von 4 bis 112 Tagen ruhiggestellt. Standardproben wurden von verschiedenen Abschnitten der distalen Partie von ruhiggestellten und nichtbehandelten Radiusknochen präpariert.

Unter Verwendung einer Beanspruchungsmaschine wurden die Präparate als unterstützte nichtfixierte Stangen bis zum Nachgeben belastet. Kein bezeichnender Unterschied zwischen der äussersten Fiberbeanspruchung, dem Elastizitetsmodulus und der bis zum Nachgeben absorbierten Energie konnte zwischen den unbehandelten und ruhiggestellten Knochen gefunden werden. Die Ergebnisse weisen darauf hin, dass die wirkliche Stärke von osteoporotischem Knochen normal ist. Die vermehrte Brüchigkeit osteoporotischen Knochens muss mit dem verminderten Knochenvolumen zusammenhängen.

Nichtbehandelter Knochen vom volarmedialen Sektor der distalen Partie des Radius zeigte gesteigerte Fiberendbeanspruchung und Elastizitetsmodulus.

## ACKNOWLEDGEMENT

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# CHANGES IN TENSILE STRENGTH CHARACTERISTICS AND HISTOLOGY OF RABBIT LIGAMENTS INDUCED BY DIFFERENT MODES OF POSTMORTAL STORAGE

*By*

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## INTRODUCTION

When carrying out mechanical investigations on components of the locomotor system it is essential to know if and how the postmortal environment affects the tissues

In a previous paper from this department (*Viidik Sandqvist & Mägi* 1965) the basic conditions for biomechanical investigations especially of the tensile strength of connective tissue were discussed Storing the intact joint at room temperature for 4 days did not affect in a statistically significant way the tensile strength characteristics of an intra articular ligament but its histological picture

Because it is not always possible to use fresh material or to maintain the conditions mentioned above investigations concerning the post mortal environment of ligamentous material were extended to the following modes of storage of ligaments without protection of surrounding tissues as in the closed joint

A A ligament or a tendon obtained at surgery should be put in a saline solution as soon as possible to prevent drying while waiting for testing

B If it is not possible to perform the experiments on the same day the specimens must be stored in saline in a refrigerator

For longer periods of storage other methods must be employed in order to avoid possible bacterial decomposition and autolysis

C A mode of storage used by some investigators is deepfreezing

D Another possibility is embalming in formaldehyde which has been done by other investigators

The present investigations are concerned with the questions as to whether or not these procedures affect the tensile strength and the histological structure of ligaments or tendons

## LITERATURE

A survey of the major literature on the mechanical properties of soft connective tissues has been given by *Viidik et al* (1965)

Here only some special points are stressed

Different investigators have arrived at conflicting results when testing the mechanical properties of connective tissue structures treated (tanned) with formaldehyde *Highberger* (1947) found a decrease amounting to 65 per cent of the original tensile strength Similar results were obtained by *Compton* (1949) who tanned fiber bundles from kangaroo tail tendons These findings are contradictory to those of *Mao & Roddy* (1950) and *Roddy* (1952) who found no changes as compared with untreated fibers in the strength characteristics of single fibres teased from tanned gross pieces kangaroo tail tendons

According to *Gustavson* (1956) these results can be explained by the theory that the interchain crosslinking produced by tanning agents does not affect the cohesive forces between the larger units because of too wide gaps between the molecular chains The findings of *Highberger* (1947) and *Compton* (1949) can then be explained by the fact that the single fiber bundles in their experiments are more effectively tanned than those in the gross piece studies and therefore subjected to case hardening

Bearing in mind that aged connective tissue may be characterized by an increased number of chemical cross linkings *Mendoza & Milch* (1964) studied the effect of a number of known cross linking agents on goatskin corium specimens They found that some of the agents caused a marked decrease in nominal tensile strength (maximal tensile load per unit original cross sectional area) but others including formaldehyde caused no significant changes Their study can be classified as belonging to the gross piece group A good review of cross linkage and aging is given by *Sinex* (1964)

Tensile strength tests of human Achilles tendons stored in formaldehyde have been made by *Stucke* (1950) who found that their stress strain curves were more uniform than those of fresh tendons Although

the final rupture of fresh tendons resulted from successive partial ruptures it occurred more suddenly in formaldehyde fixed tendons

## METHODS

The testing methods are basically the same as used by *Viidik et al* (1963) and therefore only a brief account will be given here

An increasing tensile load was applied to the anterior cruciate ligament from the knee joint of the rabbit The femur and tibia were attached by contour shaped clamps to the testing machine and all structures except the anterior cruciate ligament were severed The load was registered by an ink jet recorder (Siemens Oscillomink) from a tensile load pick up (Philips PR 9996.09) coupled to a Philips PT 1200 direct reading measuring bridge The elongation occurring in a ligament during a test was registered by Philips PR 9810 strain gauges cemented to a steel plate which deflected with elongation and coupled to a GM 5536 direct reading measuring bridge The load was measured in kiloponds and the elongation in millimeters. The following parameters were studied (i) the gross shape of the load-elongation curve (ii) its slope (tan $\alpha$) (iii) its failure energy (iv) failure load (v) elongation at failure (vi) dips in the load curve and (vi) failure site on the bone ligament bone preparation

The gross shape of the curves was subjected to cursory inspection. The slope of the load-elongation curve in the first linear portion was calculated by the formula for tan $\alpha$ for a straight line The failure energy was calculated as the area beneath the plotted load-elongation curve which was measured with a planimeter The remaining values were read from the recordings.

Standard statistical methods were employed Differences between the control group and the four treated groups were sought by means of Student s t tests one by one (slope of the load-elongation curve failure energy failure load, elongation at rupture and the frequency of dips in the load curve) The rupture site distributions were subjected to Fischer s exact test

The ligaments and their bone attachments were also subjected to histological investigation using standard methods, utilizing decalcification in formic acid, paraffin embedding and Ehrlich s haematoxyline stain.

## MATERIALS

The material used in this investigation consisted of 32 ligaments from the knees of 16 rabbits. The material was divided into 4 groups of 8 knees each and treated as follows (1) one group of knees was stored in 0 9 per cent saline solution at +20 C for 5 hours before testing with the joint opened to expose the ligament to the saline solution and to simulate conditions between excision at operation and testing (2) a second group of knees was stored the same way for 24 hours at +4 C (3) a third group with the joint intact was stored at −20 C for a week and then rapidly thawed out in water at +3 C and (4) the fourth group was stored in 10 per cent formaldehyde for 6 days with the ligament exposed to the fluid. The control material consisted of the same 14 ligamentous preparations used by *Viidik et al* (1965) All rabbits were subjected to X ray examination and only adult animals as revealed by fusion of the proximal tibial epiphysis were used.

Eleven supplementary ligament preparations were weighed immediately after excision and then stored in saline like those in group B After removal of surface water the preparations were weighed again and following vacuum desiccation determinations were made of the dry weights

## RESULTS OF THE BIOMECHANICAL TESTS

The mean values and standard errors together with statistical analysis of the different parameters are given in Tables 1 and 2 The values of the single observations are given in Figure 1

All differences in the following account are understood to be statistically significant at the 5 per cent level of confidence and refer to the control group

*Table 1 Main table for tan α failure energy failure load elongation at failure and body weight denotes a significant difference from the controls (N)*

| Group | n | Mean values ± standard error | | | | |
|---|---|---|---|---|---|---|
| | | tan α | Failure energy kpmm | Failure load kp | Elongation at failure mm | Body weight kg |
| N | 14 | 1 53 ± 0 07 | 36 0 ± 5 9 | 26 9 ± 1 1 | 1 74 ± 0 07 | 3 04 |
| A | 8 | 1 73 ± 0 21 | 70 8 ± 7 3 | 40 3 ± 2 8 | 2 94 ± 0 31 | 3 36 |
| B | 8 | 1 18 ± 0 08 | 46 0 ± 4 0 | 27 4 ± 2 6 | 2 11 ± 0 22 | 3 41 |
| C | 8 | 1 81 ± 0 15 | 53 2 ± 4 9 | 33 2 ± 3 0 | 1 71 ± 0 17 | 2 75 |
| D | 8 | 1 06 ± 0 12 | 23 9 ± 3 1 | 19 5 ± 1 9 | 1 56 ± 0 14 | 2 91 |

*Table 2 Frequencey of dips in the curves and their magnitude together with the number of pure ligament ruptures in the different groups( the rest of the preparations are understood to have failed as femoral or tibial tear off fractures) denotes a significant difference from the controls (N)*

| Group | No of curves | Dips in the curves | | | | | No of ligament ruptures |
|---|---|---|---|---|---|---|---|
| | | Total no per group | Frequency per curve | Magnitude in kp | | | |
| | | | | min | mean | max | |
| N | 14 | 6 | 0 4 | 0 5 | 1 1 | 2 | 3 |
| A | 8 | 23 | 2 9 | 0 5 | 1 7 | 9 | 0 |
| B | 8 | 18 | 2 3 | 0 5 | 1 7 | 8 | 3 |
| C | 8 | 21 | 2 6 | 0 5 | 1 8 | 5 | 3 |
| D | 8 | 15 | 1 9 | 0 5 | 1 4 | 5 | 0 |

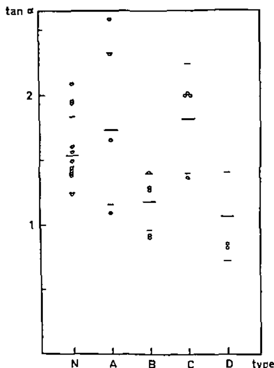



*Figure 1 a Tan α —— denotes the mean value of a parameter in a time group and – the corresponding S.D limits*

A *Storage in 0 9 per Cent Saline at +20 C for 5 Hours*

The gross shape of the load elongation curves did not differ from those of the control group and the tan α values showed no alteration The failure energy was higher in this group as was the failure load and the elongation at failure There was also a higher frequency of dips but the distribution of the site of rupture was the same

B *Storage in 0 9 per Cent Saline at +4 C for 24 Hours*

The gross shape of the load elongation curves showed no peculiarities but the tan α values were lower in this group The failure energy the failure load and the elongation at rupture did not display any aberrations There was a higher frequency of dips but the rupture site distribution was unaffected

In the ligament preparations not subjected to tensile strength tests the water content expressed in per cent of the dry weights was 146

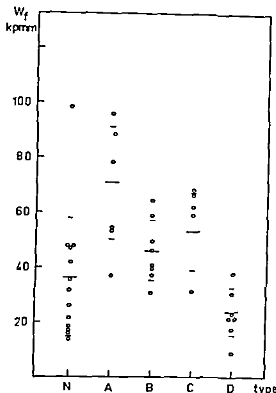



*Figure 1 b Failure energy = $W_f$ —— denotes the mean value of a parameter in a time group and – the corresponding S D limits*

± 12 After storage like the other preparations in this group the water content increased to 298 ± 39 per cent This is an increase of 60 ± 9 per cent of the weight after excision (t = 6 534) which is significant

## C Deep-frozen Storage

No variation in the gross shape of the load elongation curves occurred The tan $\alpha$ failure load and elongation at rupture values did not differ from those in the control group The failure energy was higher and there were more dips in the curves Although there were many ligamentous ruptures in this group there was no significant difference compared with the control group

## D Storage in 10 per Cent Formaldehyde

The gross shape of the load elongation curves was unaltered The tan $\alpha$ and failure load values were lower The failure energy and the elongation at failure displayed no differences There were not signifi

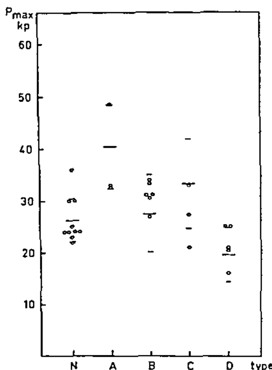



*Figure 1 c Failure load = $P_{max}$ —— denotes the mean value of a parameter in a time group and – the corresponding SD limits*

cantly more dips in the curves and no differences were found in the rupture site distribution

## HISTOLOGICAL INVESTIGATION

The histological part of the investigation was restricted to posterior cruciate ligaments stored in various ways while the anterior cruciate ligaments were subjected to tensile strength tests as well The following account summarizes the characteristic features in the histological picture as displayed in a majority of sections in the groups

We were not able to find conclusive differences between the features of the collagenous fibres the ground substance and the fibrocytes in the different groups

However in the majority of slides from preparations stored in formaldehyde the fibrocytes were more heavily stained than in the deep-frozen ones and especially those stored in 0 9 per cent saline In the latter group the fibrocytes in the more superficial layers of the liga

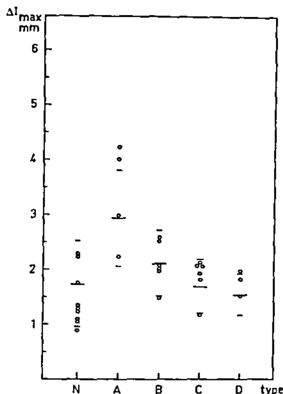



*Figure 1 d Elongation at failure = $\Delta l_{max}$ —— denotes the mean value of a parameter in a time group and – the corresponding S D limits*

ments had vanished or their loci were represented by darker areas (Figures 2–4)

The collagenous fibres in the formaldehyde treated group formed easily demonstrable parallel bundles interspersed by rows of ellipsoid fibrocytes The same was generally true for the deep frozen ligaments Ligaments stored in saline on the other hand often displayed bundles with no sharp contours But even here the parallel arrangement of fibres was evident (Figures 5 6)

Compared with the preparations in the time factor study by *Vidik et al* (1965) the features in the group stored in formaldehyde correspond well with the 0 hour group The deep frozen ligaments resemble those in the 2 hour group while the ligaments stored in saline display features similar to those in the 2 and 6 hour groups (Figure 7)

The ligaments subjected to tensile strength tests show more frequent and more extensive partial ruptures in the deep frozen and the saline treated groups than in the formaldehyde treated one

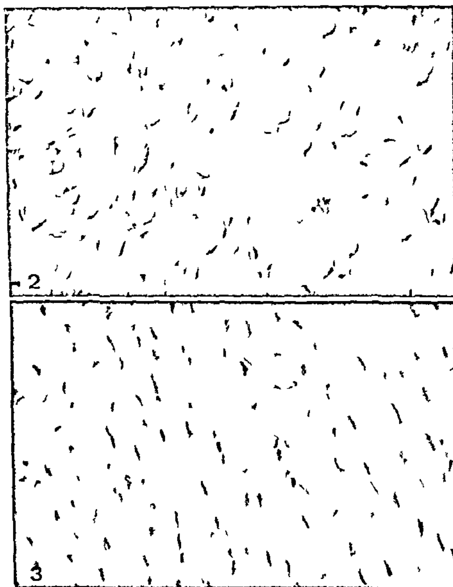
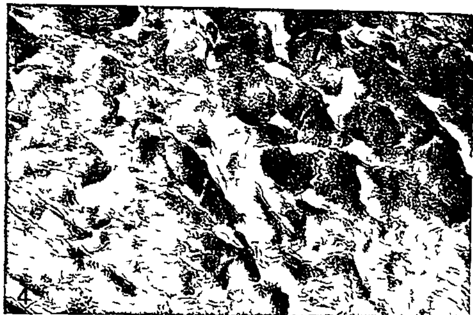



*Figure 2 Section from a deep frozen ligament The fibrocytes are preserved but are less well stained (3[illegible]3 ×)*

*Figure 3 Section from ligament stored in formaldehyde The fibrocytes are well preserved and well stained The collagen bundles are coherent (3[illegible]3 ×)*



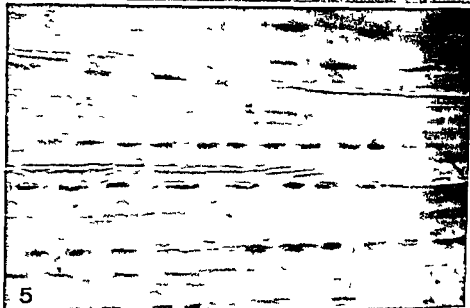




*Figure 4* Section from a ligament stored for 24 hours in saline Most of the fibrocytes have vanished The collagenous bundles seem swollen and less coherent (363 ×)

*Figure 5* A longitudinal section from a ligament stored in formaldehyde displaying the orderly arrangement and the ellipsoid fibrocytes (363 ×)

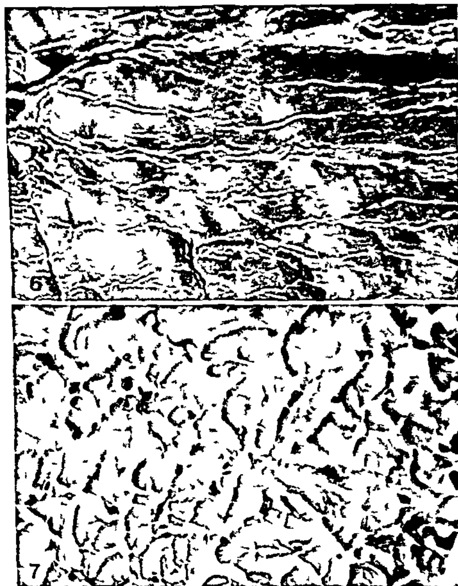


*Figure 6* *Section from a ligament stored in saline for 24 hours Cf Figure 5 (363 ×)*

*Figure 7* *Transverse section from a ligament stored in an intact knee joint for 24 hours (467 ×) [from Viidik et al 1965]*

## DISCUSSION

When performing biomechanical experiments it is essential to evaluate basic factors acting on the tissue investigated In a previous paper from this department *Viidik et al* (1965) investigated the influence of post mortal changes on the tensile strength characteristics as well as on the histological appearance of intraarticular ligaments in intact rabbit knee joints stored at room temperature Although changes in the histological picture appeared after 6 hours the tensile strength was not extended this study feeling that it is not always possible to adhere to the conditions mentioned above especially when using human tissues obtained at surgery and having in mind that earlier investigatiors have utilized different modes of storage The aim of the present investigation was to search for suitable methods of storage Storage in saline at room temperature (+20 C) for 5 hours and in a refrigerator (+4 C) for 24 hours in a deepfrezer (—20 C) and finally in 10 per cent formaldehyde were tested

The groups stored in 0 9 per cent saline for 5 and 24 hours deviated significantly in important parameters from the control group As this was not true for the 6 and *24* hours groups in the above mentioned investigation (*Viidik et al* 1965) the saline must in some way have altered the tensile strength characteristics of the collagenous ligaments *Investigators of the chemistry of collagen have used different concentrations* of sodium chloride to alter the chemical behaviour of collagen but here we refrained from guesses as no chemical studies *were included in the present investigation*

In surgical practice saline is considered to be mild to different tissues and is frequently used as a moistener As judged by the biomechanical tests it affects the tensile strength of collagenous tissue considerably in biopsy and autopsy specimens and it does not prevent imbibition of water by the tissues

Besides the above mentioned possibility of solubilisation of collagen the imbibition of water must be considered According to *Elden et al* (1962) the mechanical stability of soft connective tissue is dependent on a balance of cohesive and dispersive forces They consider the swelling to be mainly the result of osmotic pressure one of the dispersive forces

Therefore 0 9 per cent saline is not a mild and non harming agent with regard to the mechanical properties of connective tissue its water content its structure and its stainability in histological investigation

The same is applicable to the deep-frozen group where the water crystallization and thawing may be the interfering factor

Storing or rather tanning in formaldehyde certainly affects the molecular structure of collagen as was evident from the significant deviations from the control group in our series

The conclusion from this investigation is that mechanical tests of collagenous tissue removed at surgery and without protection of the surrounding tissue must be done immediately If this is not feasible some adequate method of storage must be developed Possibly some liquid like blood plasma or synovial fluid providing low exchange gradients of different molecules can be used

When carrying out histological investigations the material must be fixed immediately after removal at surgery if evaluation of finer cellular structures stainability etc is essential


## SUMMARY

The influence of the following modes of postmortal storage on tensile strength characteristics and histology of rabbit ligaments were studied (A) in saline for 5 hours +20 C (B) in saline for 24 hours +4 C (C) deep-freezing (D) in 10 per cent formaldehyde In each group 8 knees were included The fresh control material consisted of 14 knees

The following parameters were employed (i) the gross shape of the load elongation curve (ii) its slope (tan $\alpha$) (iii) its failure energy (iv) failure load (v) elongation at failure (vi) dips in the recorder s load curve and (vii) failure site on the bone ligament bone preparation

Standard histological methods were used

None of the modes of storage proved satisfactory for the preservation of the tensile strength characteristics of the fresh soft connective tissue

Only storing in formaldehyde (in fact fixing in it) proved satisfactory for histological studies

These findings are discussed and it is concluded that biomechanical tests on collagenous tissue removed at surgery must be performed with no time lapse



## RÉSUMÉ

L influence des modes suivants de stockage post mortel sur les caractéristiques de la force de tension et l histologie des ligaments de lapins a été étudiée (A) dans l eau salée pendant 5 heures +20 C (B) dans l eau salée pendant 24 heures +4 C (C) à l état surgelé (D) dans 10

pour cent formaldehyde Chaque groupe comprenait huit genoux Le materiel frais de controle consistait en 14 genoux

Les parametres suivants ont ete utilises (i) forme approximative *de la courbe d elongation en charge (ii) son inclinaison (tang α)* (iii) son énergie de rupture (iv) sa charge de rupture (v) elongation a la rupture (vi) chute de la courbe de charge de l enregistreur et (vii) emplacement de la rupture sur la préparation os ligament os

Des methodes histologiques ont été utilisees

Aucune des methodes de stockage ne s est montree satisfaisante pour la conservation des caracteristiques de la force de tension des tissus conjonctifs mous frais

Seule la conservation dans la formaldehyde (en fait la fixation dans celle ci) s est montree satisfaisante pour les études histologiques

Il est discute de ces trouvailles et il est conclu que le test bio mecanique du tissu collagene extirpe chirurgicalement doit etre prati que sans delai

ZUSAMMENFASSUNG

Der Einfluss folgender Arten postmortaler Aufbewahrung auf Dehn barkeitsstarke und Histologie von Kaninchenligamenten wurde unter sucht (A) In Salzauflosung fur 5 Stunden +20 C (B) in Salzauf losung fur 24 Stunden +4 C (C) Tieffrierung (D) in 10 Pro zent Formaldehyd Jede Gruppe umfasste 8 Kniee Des frische Kontroll material bestand aus 14 Knieen

Die folgende Parameter wurden angewendet (i) *Die grobe Form der* Belastungs Verlangerungskurve (ii) ihr Abfall( Tang α) (iii) ihre Versagungsenergie (iv) Versagungsbelastung (v) Verlangerung bei der Versagung (vi) Einkerbungen in der Belastungskurve des Rekor*ders und (vii) Sitz* des Nachgebens am Knochen Ligament Knochen Praparat

Normierte histologische Methoden wurden verwendet

Diese Befunde werden besprochen und man schliesst dass bio chemische Untersuchungen an kollagenem Gewebe das anlasslich chirurgischer Eingriffe entfernt wird ohne Zeitverlust ausgefuhrt werden mussen

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Acta orthop. Scandinav. 37, 156–165, 1966

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# TELEMETRY OF MYO POTENTIALS

## *A Preliminary Report on Telemetring of Myo Potentials from Implanted Microcircuits for Servo Control of Powered Prostheses*

*By*

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The possibility of using myo electric potentials for control of a powered prosthesis was first realized by *Battye, Nightingale & Whillis* (1955). In a previous paper (*Hirsch, Kaiser & Petersen* 1964) regarding bio-electrical control in a servo system, we discussed the possibilities and difficulties in using different types of electrodes for receiving the muscle action potentials. We also mentioned the desirability of creating a small electronic circuit for implantation under the skin in order to obtain a closer contact with the muscle and a minimum of disturbance from neighbouring muscles. With such an implanted electrode we would be able to exclude the interference associated with fixation and maintenance of surface electrodes. Recently *Bottomly* (1965) discussed the matching of amplifiers to electrodes showing resistance of up to 200 kOhm.

Regarding an implantable circuit, some properties should be taken into consideration. It should be of a suitable size, probably not exceeding a volume of 0.5 $cm^3$. It should have a shape with due regard to the electric input terminals and the surrounding tissues. Considering that the implantation will be for a long period, built-in batteries must be avoided and the necessary powering be obtained from an external source in the mW power range. Furthermore, the external covering has to be of a material which could be well tolerated by the tissues.

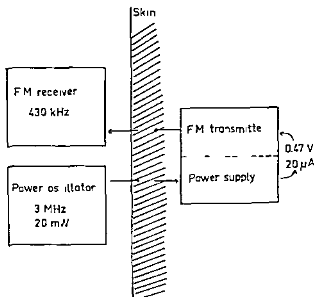



*Figure 1 Block diagram showing on the left the external power oscillator yielding energy to the power receiver of the implanted circuit on the right This power receiver converts a fraction of the power oscillator output to d c voltage which is energizing an FM transmitter The transformed bio-activity from the FM transmitter is received outside the body by an FM receiver*

## TECHNICAL DESCRIPTION OF THE MICRO CIRCUIT

The arrangement is shown in the block diagram of Figure 1 An external 3 MHz power oscillator yielding an energy output of about 20 mW is situated on the skin surface at a distance of between 1.5–4 cm from the implanted circuit The implanted circuit consists of two parts—1/ a power receiver which converts a fraction of the power oscillator output to d c voltage which is energizing 2/ a small transistor oscillator which is frequency modulated bio-electrically by means of capacitor diodes The bio-activity is thus transformed to frequency modulated output at a center frequency of 430 kHz which is received outside the body by means of a F M receiver circuit tuned for the said center frequency

Figure 2 shows a diagram of the micro-circuit A small center tapped coil 1a and 1b having a ferrite core with a diameter of 1.5 mm receives energy inductively from the external power source A small capacitor 20 30 pF is used to tune the circuit to the frequency of the

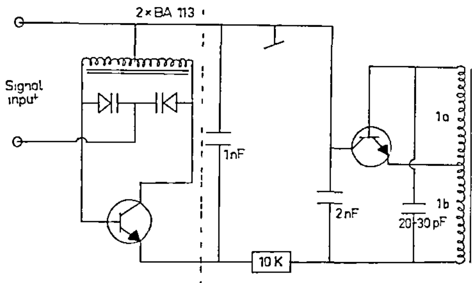



*Figure 2 A Diagram of the micro circuit fully described in the text*

power oscillator The coil 1a provides a steering signal for a miniature epitaxial silicon transistor in such a way that this transistor works as a controlled rectifier Only when the base emitter voltage from the coil 1a exceeds 0 5 V can rectification or conduction take place over the emitter collector circuit of the transistor Compared to a simple diode arrangement two advantages have been obtained 1) the avoidance of a voltage drop of about 0 6 V which would always have taken place over a silicon diode In the present arrangement the emitter collector voltage drop is less than 0 06 V provided the necessary steering voltage exists over the base emitter circuit The necessary energy in the steering circuit is only a fraction of the corresponding diode loss in a conventional circuit 2) an effective voltage regulation is obtained because an energy surplus immediately is dissipated over the base emitter circuit

Two capacitors 2nF and 1nF form together with a 10 kOhm series resistor the termination of the power supply of the micro circuit The F M frequency modulated oscillator is connected to two capacitor diodes The coil of this oscillator is wound on a core of the same type as the receiving coil and center tapped for the input of the supply current It should be noted that the base and the collector of the transistor oscillator are kept at the same d c potential In this way a very economic and stable circuit is obtained The necessary feeding

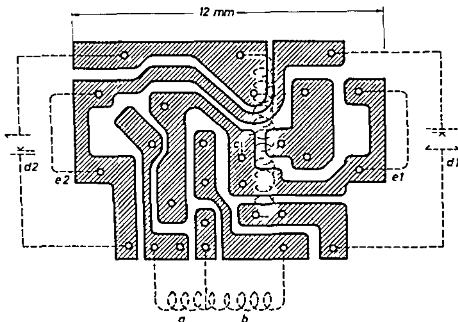



*Figure 3 The etched circuits of the implanted system a b) a center tapped receiver coil c) a center tapped transmitter coil d1 d2) capacitor diodes e1–e2) input terminals*

voltage is only 0 47 V and it oscillates at a peak to peak voltage of about 0 5 V with a current consumption down to 20 $\mu$A The micro circuit is nearly drift free When the distance varies in the transmission range 1 5–4 cm the total center frequency change is maximum 300 Hz

Figure 3 shows the etched circuits of the implanted system As an aid for the reader a few of the components are symbolized a b the center tapped receiver coil c/ the center tapped transmitter coil d1 d2 the capacitor diodes e1 e2 input terminals (U shaped gold wires 0 35 mm in diameter) The base plate consists of 0 25 mm epoxyglassfibre copper clad laminate with a length of 12 mm and a width of 10 mm The receiving coil is mounted along the 12 mm edge of the base plate and the transmitting coil is placed perpendicular to the receiving coil

The geometry of the coil arrangement is shown in Figure 4 In order to obtain a reasonable electromagnetic efficiency a magnetic concentrator arrangement has been made for the receiving coil and the transmitting coil as well The receiving coil a b is terminated by two concentrators g1 and g2 The transmitting coil c uses the core

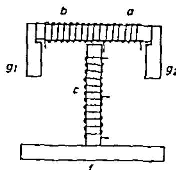



*Figure 4. Showing the arrangement of the coils in order to obtain reasonable electromagnetic efficiency. a b) receiving coil terminated by two concentrators g1, g2. c) transmitting coil using the core of the receiving coil as a concentrator at the one end and a ferrite rod at the other end.*

of the receiving coil as concentrator at the one end and a bare ferrite rod as concentrator at the opposite end. This concentrator arrangement improves the receiving and transmitting efficiency by a factor of about 1.5.

In the space between the concentrators are placed commercially available miniature components. After mounting and preliminary tests, the components are embedded in epoxy (araldite) and after final mechanical corrections the whole unit (except the protuding gold electrodes) is reembedded in epoxy.

Initially we intended to use silicone rubber for the final encapsulation. Unfortunately the mechanical durability was poor, possibly because this type of rubber has shown an insufficient mechanical resistance around the protruding electrode wires.

## PRELIMINARY RESULTS OF A CLINICAL TEST OF THE IMPLANTED MICRO CIRCUIT

The aggregate has been clinically tested in two persons, the one a volunteer, the other a 30 years old male who two years ago had his right arm amputated about 20 cm distal to the elbow. In both cases the implantation was performed under local anaesthesia. The implant was placed near the extensor muscles immediately superficial to the overlying fascia at a depth below the skin surface of 1–2 cm. In the volunteer it was removed immediately after having been tested at the laboratory. In the patient the forearm during the first 3–4 days after the operation showed a slight edema at the site of surgery, which thereafter completely disappeared. He had no further discomfort from the



*Figure 5 X ray picture of the implanted aggregate in the patient*

implantation. The implanted micro-circuit was electrically tested immediately and after a period of 10 days. Shortly thereafter the transmitted signals appeared to be of a less satisfactory quality. For that reason it was removed for technical control. It was now observed that the implant was surrounded by a membrane about 0.2 mm thick. On histologic examination the membrane was shown to consist of unspecific granulation tissue. Technical control revealed an extraneous

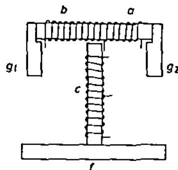



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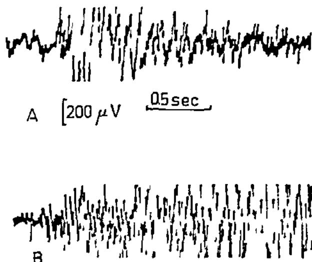



*Figure 7 Transmitted activity from the patient (extensor muscles of the forearm) obtained A) one hour after the implantation B) ten days after the implantation*

an earlier report (*Hirsch, Kaiser & Petersen* 1964) the value of the low frequency spectrum as a source of information is poor Therefore it is of greater importance to examine the high frequency portion of the spectrum From this examination it emerged that the 800 Hz and 1600 Hz activity was far better represented in the transmitted activity In fact it was shown that the 800 Hz and 1600 Hz activity was 40 per cent and 300 per cent higher respectively in the activity transmitted from the implant

Figure 7 illustrates the transmitted activity from the patient In this case also the implant was placed in connection with the extensor muscles of the forearm A shows the activity obtained about one hour after implantation B shows the activity ten days later Contrary to the result from the volunteer the spectral distribution of the transmitted activity from the amputee showed less high frequency activity than that obtained with skin electrodes When the analyzed activity in A is compared to that in B a minor increase in the high frequency output of the latter was detected This might be due to an increase in the effective electrode area caused by the presence of anaesthetic fluid and edema in close time relation to the surgical procedure

## COMMENTS

Of course a representative series of amputees must be investigated for a long period in order to state the possible value of external powered implanted micro circuits for the control of powered prostheses. However, it is apparent from the above that such a type of telemetring is not too difficult to perform. A RF powered implanted unit has been described by *Ko* (1964). This unit consists, however, of two interconnected but separate elements, the one acting as a RF receiver/power supply, the other as a frequency modulated transmitter. The two elements are mechanically and electrically interconnected by means of a 4 cm flexible wire.

In future work the shape of the implant should be an object of more attention. In order to avoid possible liquid accumulation around the electrodes these should have the shape of a lens or a bean. At the same time a reduction of the total volume of the implant to about 0.2 or 0.25 cm³ is desirable and we think possible when changing from conventional miniature components to monolit circuits. It is our intention to have the active elements encapsulated in a miniature glass container in order to avoid a possible degradation of the semiconductors after long term exposure to tissue fluid.


## SUMMARY

A technical description is given of an implantable micro circuit telemetring myo potentials for servo control of powered prosthesis.

Preliminary results are given of the clinical observations and the electrical tests of the telemetred myo signals.

## RESUMÉ

Il est donné une description technique d'un micro-circuit implantable télémesurant le myopotentiel du servo contrôle des prothèses powered.

Des résultats préliminaires sont donnés sur les observations cliniques et les testes électriques des myo signaux télémesurés.

## ZUSAMMENFASSUNG

Eine technische Beschreibung eines einpflanzbaren Mikrostromkreis fernmessen den Myopotentials zur Servokontrol von aufgeladenen Prothesen wird gegeben.

Vorlaufige Ergebnisse der klinischen Beobachtungen und der elektrischen Proben der ferngemessenen Myosignale werden gegeben

This investigation has been supported by grants from the Swedish Medical Research Council the Insurance Company FOLKSAM and the Medical Society of Gothenburg Sweden

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# ELECTROMYOGRAPHY IN CASES OF CONGENITAL AND TRAUMATIC ARM AMPUTATIONS

*By*

INGEMAR PETERSÉN

Received 24 xii 65

*Battye Nightingale & Whillis* (1955) were the first to recommend the use of myo electric potentials for the control of powered prostheses A model of a prosthesis in which signals transmitted by skin electrodes has been described by *Kobrinski* (1960) and is subject to further exposition by *McKenzie* (1965) The use of myo signals has also been discussed in works by *Bottomley* (1962) *Bottomley Kinnier Wilson & Nightingale* (1963) Recently (1965) Bottomley discussed the matching of amplifiers to electrodes showing a resistance up to 200 kOhms The suitability of the myo signals is far as their composition of frequency is concerned has been discussed by *Battye et al* (1955) and by *Horn* (1963) and more particularly by *Hirsch, Kaiser & Petersen* (1965)

Considerably more searching information than up to the present is however required regarding the characteristics of the muscular action potentials from muscles in the region of amputation and proximal muscles The present work refers to such an investigation of arm amputated subjects in which cases conventional EMG frequency analysis of the EMG signals and determination of the muscle temperature have been performed

## MATERIAL AND METHODS

The material consists of 50 patients from the department of orthopaedics who have previously been subject to arm amputation As will be seen from Figure 1 there were 42 cases of traumatic arm amputations 35 men and 7 women of ages ranging from 20 to 72 years Amputation of the arm had been performed from 5 to 68 years previously with the exception of two cases where it had been carried out 4 months and 12 months earlier respectively There were eight cases of congenital amputations

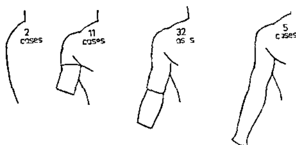



*Figure 1*

| | 50 cases | | |
|---|---|---|---|
| Traumatic amputation | 42 | 35 ♂ | 7 ♀ |
| Congenital amputation | 8 | 2 ♂ | 6 ♀ |
| Right side | 31 | | |
| Left side | 19 | | |

—2 men and 6 women of the ages 10 to 47 years In 31 cases the amputation was on the right side and in 19 cases on the left In 2 cases a complete exarticulation was performed in 11 cases the amputation was performed on the brachium in 32 cases on the forearm and in 5 cases below the wrist

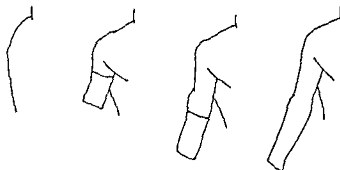
In all the cases an EMG test of routine type was made on the remaining muscles belonging to the extensor and flexor group of the forearm M brachioradialis M biceps brachii and M triceps brachii M deltoideus and M trapezius Coaxial needle electrodes with an outer diameter of 65 mm (Disa) were used The action potentials were recorded by a Disa machine In 26 cases a frequency analysis of the EMG signals was carried out by means of a method described by *Kaiser* & *Petersén* (1965) In this method the signals are filtered by means of octave filters the output of which is used to express the spectral frequency distribution of the muscle action potentials The center frequencies of the octave filters were 50 Hz 200 Hz 800 Hz and 1600 Hz and the spectral distribution expressed as the logarithm of the ratio of the different filter outputs as compared to the 200 Hz output

In 19 cases the temperature of a muscle in the stump remaining after the amputation was determined for comparison with that of the corresponding muscle on the other side The temperature recordings were made by means of a thermo element type of instrument from ELLAB Copenhagen

## RESULTS

### *The Results of Electromyographic Investigation*

The result of the routine EMG test can be seen in Figure 2 which shows the distribution of normal EMG findings as well as findings of EMG signs of lower motoneuron lesion The distribution of these findings appear to be more or less as anticipated namely that the majority of the lower motoneuron lesions have been diagnosed in



EMG findings

| | Small signals | Normal | Lower motoneuron lesion | Normal | Lower motoneuron lesion | Normal | Lower motoneuron lesion |
|---|---|---|---|---|---|---|---|
| Trapezius | 2 | 10 | | 24 | | 2 | |
| Deltoideus | | 9 | 1 | 22 | | 2 | |
| Biceps | | 4 | 2 | 29 | 1 | 3 | |
| Triceps | | 1 | | 22 | 1 | 2 | |
| Forearm | | | | | | | |
| Extensors | | | | 17 | 10 | 5 | |
| Flexors | | | | 20 | 8 | 5 | |
| Brachioradialis | | | | 18 | 7 | 4 | |

*Figure 2*

muscles directly associated with the region of amputation. In some solitary cases the nature of the injury caused signs of lower motoneuron lesions to appear in more proximal muscles also.

Figure 3 shows some examples of EMG findings. *B* shows the typical EMG sign of voluntary contraction in cases of lower motoneuron lesion: in this case amputated on the brachium; the EMG has been recorded from M. biceps brachii. For the sake of comparison *A* shows the normal interference activity from M. biceps brachii on the opposite arm. *C* also shows a somewhat reduced activity. The potentials show here to a great extent a polyphasic form, as illustrated in the separate picture to the extreme right. This surplus of polyphasic potentials may constitute an expression of a reinnervation process and was noted in this material in six different muscles. Fibrillary action potentials were observed in three muscles only. *D* shows the amazingly favourable activity from islands of trapezius muscle left behind in one of the

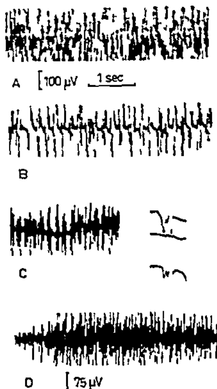



*Figure 3 A) normal motor unit activity from M. biceps brachii on the non-amputated side. B) M. biceps brachii on the amputated side in the same patient as in A). Reduced number of potentials on voluntary contraction as in the case of lower motoneuron lesion. C) diminution of motor unit activity on voluntary contraction of muscles in the region of amputation. To the extreme right: polyphasic potentials. A surplus quantity of polyphasic potentials in this case may be a sign of reinnervation. D) activity from a small residue of a muscle corresponding to the position of M. trapezius in an exarticulated patient.*

exarticulated cases. In neither of these two cases could these islands of muscle be activated in response to a call for voluntary contraction. When, on the other hand, the patient on request contracted the trapezius on the uninjured side, a simultaneous activation of the muscle islands on the exarticulated side could be observed.

In one particular case the patient had a certain amount of trouble in mobilizing the muscles left behind to perform a contraction, although the muscles in the stump region were in a good state of preservation. The case referred to a forearm amputation at the age of three in a patient now 71 years old.

Apart from these EMG findings, a certain increase in duration of the observed muscle potentials was noted as the only divergent finding in 20 muscles. In order to determine the significance of such an increased duration of potential it would be necessary to collect a number of potentials from different needle positions in muscles on the side of amputation for statistical evaluation and comparison with corresponding muscles

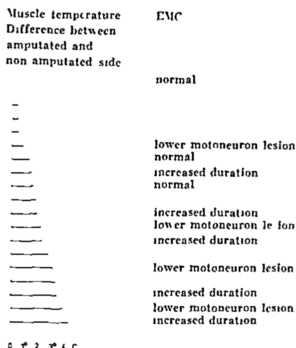



*Figure 4 Difference in muscle temperature between amputated and non amputated sides in collation with EMG findings in the muscles on the amputated side where the temperature of the muscle has been measured*

in the other arm or with known normal material published Since however parts of muscles left behind often are of insignificant size and in view of the fact that the patients as a rule are rather sensitive to needle pricks in the stump region it has not been possible to assemble a sufficient amount of material of muscle action potentials to accomplish such a statistical analysis

## *Result of the Determination of the Muscle Temperature*

In 19 of the cases investigated the muscle temperature was measured in a muscle located within the stump region as well as in the corresponding muscle of the other arm The result is shown in Figure 4 The difference in temperature between the two compared muscles is shown to the left Only in the topmost case is there no difference In all the other cases the muscle temperature is lower on the amputated side In 13 of the cases the temperature difference is found to be more than 1 degree Centigrade When collating the temperature differences with the electromyographic findings to the right it will be seen that

the normal EMG findings are all located in the half section showing slight temperature differences between the amputated and not amputated sides, whereas all except two cases with lower motoneuron lesion and increased duration of potentials are to be found in the half section displaying the widest differences in temperature.

### *The Result of Frequency Analysis of the EMG Signals*

As already mentioned in the section headed "Materials and method" the frequency analysis is accomplished with the aid of a method described by *Kaiser & Petersen* (1965) in which the passband activity of each one of the 50, 800 and 1600 Hz filters is related to the activity of the 200 Hz filters. This analysis showed that there was no certain difference between right and left sides when muscles on the amputated side of the type which showed normal EMG images on routine EMG were compared with corresponding muscles on the other side. In the same way no deviations were traced on comparison of such muscles on the amputated side which on routine EMG showed somewhat increased duration of muscle action potentials with the corresponding muscles on the other side. In the matter of frequency spectrum from muscles showing electromyographic signs of lower motoneuron lesions, however, the reduction in amplitude of the 800 and 1600 Hz signals was considerably greater than in the control material and on the basis of these facts it was possible to decide that the myo-signals from muscles showing EMG signs of lower motoneuron lesion are less useful for the purpose of controlling a prosthesis. The section headed "Material and method" also mentions the spectral distribution of signals revealed via the output of the various filters expressed as the logarithm of ratio of the different filter outputs as compared with the 200 Hz filter output. The decibel scale (dB) is used to indicate the observed differences between the output levels. Thus 20 dB corresponding to a ratio of 10 is indicated by an output voltage of 2 volts corresponding to 1 V per dB. On evaluating of the results of the analysis I have taken the mean value ratios (expressed in dB) of log 800 Hz output/200 Hz output and log 1600 Hz output/200 Hz output. We then consider 15 dB as the upper determinant of acceptability for control of a servo prosthesis. The reason for this approximate limit is that a poor representation of signals in the 800–1600 range (great dB values) would demand a high amplification of the EMG which in its turn would decrease the signal to noise level. Figure [illegible] shows a divisioning of muscles on the am

| Forearm | | | | | | |
|---|---|---|---|---|---|---|
| Extensor | Flexors | Brachioradialis | Biceps | Triceps | Deltoideus | Trapezius |
| | | | − | | − | − |
| | | | | | − | − |
| | | | | | + | + |
| | | | − | − | + | + |
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*Figure 5 Mapping out of the portion of the material where conventional EMG or frequency analysis of EMG could furnish information as to the suitability (+) or non suitability (—) of the muscles for producing signals for control of powered prosthesis See text for further details*

putated side examined in the manner stated above where the symbol— means either that the stated dB figure is higher than 1σ or that routine EMG test shows signs of lower motoneuron lesion or both whereas the symbol + indicates that the dB value is 1σ or less in a muscle which on routine EMG shows no sign of lower motoneuron lesion The

most fruitful section of our material deals with patients who have been amputated below the elbow. From the sketches it can be seen that six of these have no muscle in the forearm stump which is able to produce suitable signals according to our criteria. In all five patients show suitable signals from at least two muscles in the forearm stump. On the other hand not less than 13 of the 19 cases have at least three muscles on the amputated side which can produce suitable signals. Obviously the number of suitable muscles indicated in the illustration constitutes a minimum number since in each individual case only certain muscles of the flexor and extensor group of the forearm have been subject to investigation.

## DISCUSSION

The present investigation has produced evidence to support the fact that it is possible with the aid of electromyography and frequency analysis of the myopotentials to effect a mapping out of the muscles which might be of use in producing signals for control of a powered prosthesis. Certain data from the present investigation may be subject to modification as some of the amputations were performed a long time ago. In the present work, therefore, there is no doubt that a smaller number of findings of so called denervation potentials, as well as a reduced quantity of polyphasic potentials as expressions for reinnervation, exist than would be the case in the course of an examination closely associated with the amputation. I also plan to extend the investigation by adding a suitable number of cases of more immediate association with the amputation.

Of special interest is the 71 year old patient who had his forearm amputated at three years of age. During the examination he had difficulty in effecting a reasonable voluntary contraction although the muscles in the stump region were in a good state of preservation. It is possible that disturbances in the central innervation were of significance in this case, possibly due to the early date of the amputation. Similar innervation disturbances have been stated to be much more common in material of leg amputations (*Blom, Hagbarth, Lemperg & Ottoson* 1965).

On comparison with corresponding muscles on the non amputated side, the temperature of muscles located within the amputation region was found to be lower. This may possibly explain the comparatively common finding of muscle action potentials of extended duration. It

could for example be assumed that the lower muscle temperature has a special influence on the most peripheral nerve branches resulting in the spreading of the time taken for the nerve transmission which in turn may result in an extension of the duration of muscle potentials. Such an extended duration of the muscle action potentials due to a lowering of the muscle temperature has previously been proved by *Buchthal, Pinelli & Rosenfalck* (1954).

## SUMMARY

Fifty cases of arm amputated patients have been subject to investigation: traumatic arm amputation in 42 cases, 35 men and seven women; congenital arm amputation in eight cases, two men and six women. In 31 cases amputation had taken place on the right arm and in 19 cases on the left. In two cases it was a matter of complete exarticulation, in 11 cases amputation somewhere above the elbow, in 32 cases somewhere below the elbow and in 5 cases below the wrist.

In all the cases a routine EMG test was carried out. Signs of lower motoneuron lesion appeared in a number of examined muscles, principally within the region of the stump. Frequency analysis of the EMG signals was also carried out according to the method described by *Kaiser & Petersen* (1965). On the basis of the result of the conventional EMG test and frequency analysis an attempt was made to map out the muscles on the amputation side which will be suitable or unsuitable for producing signals for control of powered prosthesis.

## RÉSUMÉ

50 cas de malades amputés du bras ont fait l'objet d'un examen: amputation traumatique du bras dans 42 cas, 35 hommes et 7 femmes; amputation congénitale du bras dans 8 cas, deux hommes et six femmes. Dans 31 cas il était question de l'amputation du bras droit et dans 19 cas du bras gauche. Dans deux cas il s'aggissait d'une exarticulation complète, dans 11 cas l'amputation avait eu lieu quelque part au dessus du coude, dans 32 cas quelque part au dessous du coude et dans 5 cas au dessous du poignet.

Dans tous les cas examen routinier par électromyographie (EMG) a été pratiqué. Des signes de lésion de neurone moteur inférieur sont apparus dans un certain nombre de muscles examinés, principalement

dans la region du moignon Une analyse de la frequence des signaux EMG a aussi ete pratiquee selon la methode decrite par *Kaiser & Petersen* (1965) Sur la base du resultat du test conventionnel EMG et de l analyse de la frequence on a tente de voir si les muscles du cote de l amputation sont aptes ou non a produire les signaux de controle des protheses

## ZUSAMMENFASSUNG

Funfzig Falle von Arm amputierten Patienten wurden untersucht traumatische Armamputation in 42 Fällen 35 Manner und sieben Frauen angeborene Armamputationen in acht Fallen zwei Männer und sechs Frauen In 31 Fallen hatte die Amputation am rechten und in 19 Fallen am linken Arm stattgefunden In zwei Fallen handelte es sich um vollständige Exartikulation in 11 Fällen um Amputation oberhalb des Ellbogens in 32 Fallen distal vom Ellbogen und in 5 Fällen distal des Handgelenkes

In allen Fallen wurde eine routinemässige EMG ausgeführt Zeichen von Beschädigung des distalen Motorneuron zeigten sich in einer Anzahl der untersuchten Muskeln Hauptsahlich in der Stumpfregion Frequenzanalyse der EMG Signale nach der von *Kaiser & Petersen* (1965) beschriebenen Methode wurde ebenfalls vorgenommen Auf der Basis von konvetionellen EMG Prufungen und der Frequenzanalyse wurde der Versuch unternommen die Muskeln der amputierten Seite herauszufinden die geeignet oder ungeeignet sein würden Signale zur Kontrolle einer aufgeladenen Prothese hervorzubringen

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# ELECTROMYOGRAPHIC STUDIES ON THE VERTEBRAL PORTION OF THE PSOAS MUSCLE

## *With Special Reference to its Stabilizing Function of the Lumbar Spine*

*By*

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With the introduction of a method for *in vivo* disc pressure measurements information can be obtained of the load on the lumbar intervertebral discs in different positions of the body (20). In these measurements it was found that in the upright sitting position 140 kg is carried by the third lumbar disc in a 70 kg man, while in the upright standing position this load is 100 kg.

The spinal column, which serves as a sustaining rod for the maintenance of the upright position of the body, was considered by *Lucas & Bresler* (1961) (14) to have both an intrinsic and an extrinsic stability. Intrinsic stability is provided by the alternating vertebral bodies and discs of the spine which are bound together by ligaments, while extrinsic stability is provided by the paraspinal and trunk muscles. The trunk muscles, especially those of the abdomen, form a contractile muscular wall about the body compartments which is capable of compressing the viscera. With the contraction of these muscles the intracavitary pressures are increased, aiding in many bodily functions such as childbirth, respiration, return of venous blood, and, as has been shown, stabilization or support of the spine (2, 7, 9, 18). No mention of the psoas muscle was made in these studies.

The isolated ligamentous spine behaves like a modified elastic rod (14). When it is fixed at the base, its critical load—i.e. the greatest vertical load it can sustain on top of the first thoracic vertebrae without buckling—is only 2 kg. The stability of the spine in the living human being is therefore dependent largely on the extrinsic support provided

by the trunk musculature. The lack of inherent or intrinsic stability of the vertebral column and the importance of the trunk muscles are clearly demonstrated if one tries to hold an unconscious person upright.

*Sypher* (1960) (23) thought for theoretical reasons that the psoas muscle was called upon to compensate for imbalance between anterior abdominal muscles and posterior spine muscles in stabilization of the lumbar portion of the spine and to be active if full power is to be derived from more distal muscles in the extremities.

*In vivo* discometry demonstrated that a relationship exists between the load on the middle lumbar discs on the one hand and the position of the subject and weight of the body above the level measured on the other hand (19, 20). In the unsupported sitting position this can be written

Eq. (1) $P(kg) = 30 + 2.8\,W + 3.6\,W \sin \alpha$

where P is load on the lumbar disc, W the bodyweight above the level measured and $\alpha$ the angle of forward leaning if any.

In the standing position the relation is

Eq. (2) $P(kg) = 20 + 2.1\,W + 3.6\,W \sin \alpha$

The results from these measurements can be summarized as in Figure 7.

According to the findings of *Braune & Fischer* (1889) (4), *Dempster* (1955) (8) and *Asmussen & Klausen* (1962) (1) gravitational forces alone cannot explain the loads in the upright standing and sitting positions found from these measurements and with the knowledge that the electromyographic activity of the sacro spinalis and anterior abdominal musclegroups are relatively small in these positions (3, 5, 10, 11, 12, 17, 21, 22) other muscular forces than those mentioned should be considered. *Lucas & Bresler* (14) found it improbable that the intrinsic stability of the spine itself offered by the ligaments and intervertebral discs is enough to stabilize the body in the positions outlined above.

The psoas muscle arises at the transverse processes of the 12th dorsal and all the lumbar vertebrae and at the lateral bodies and intervertebral discs at the same levels. It is attached together with the iliacus portion of the muscle to the femur somewhat above and to the lesser trochanter.

Previous investigations on the function of the ileopsoas muscle has mostly centered around the hip joint. It has been demonstrated that

the ileopsoas is a flexor of the hip joint (3 6) From their electromyographic studies these authors also concluded that the muscle is neither an inward nor an outward rotator of the hip as was previously said (13)

Very few reports have been given on the function of the psoas muscle on the vertebral column although some authors like *Michele* (16) and *Sypher* (23) believed for theoretical and anatomical reasons that the psoas played an important role in different patterns and forms of posture *Basmajian* (3) investigated four subjects with a needle electrode inserted in the psoas major muscle and revealed activity in the upright standing position He called it an active postural muscle

The reasons for the scanty reports found in the literature can be summarized as was done by *Close* (6) who found the recording of psoas EMG s hazardous and dangerous In this study a roentgen image intensifier was used In three of the nine cases the test had to be interrupted because of discomfort One of these subjects had a vasovagal syncope *The other subjects took part in the experiment after a* few minutes rest

Since it is obvious that gravitational forces alone are insufficient to explain the size of the load in both upright standing and sitting positions found at discometry and with the previous knowledge that the electromyographic activity of the sacro-spinalis and anterior abdominal muscle groups are relatively small in the sitting and in the standing positions studied (3 10 11 12 17 21) this investigation on the vertebral portion of the psoas muscle was carried out The anatomical relation of the psoas muscle to the lumbar spine is such that activity in the vertebral portion of this muscle will exert a compressive force on the spine

## MATERIAL AND METHODS

Single coaxial electrodes were used and inserted into the psoas muscle via the posterior lumbar sympathetic block approach (Figure 1) The position of the needle was checked by anterior posterior and lateral roentgenograms (Figure 2) *The eventual risks were reduced and the insertion helped by the use of a roentgen image intensifier* The needle was always inserted from the right side at the level of the third intervertebral disc (Figure 1) One electrode was also inserted into the right sided sacro-spinalis group of muscles at the same level Recordings of the activity were made using a Disa electromyograph

The material consists of eight normal volunteers four men (age ?1 30 30 47 y ) and four women (age ?3 24 ?5 34 y ) The following positions were studied

1 Upright sitting without support
  Upright sitting without support 10 kg in each hand
3 Sitting and forward leaning by flexion in the hip joints by 20 degrees.

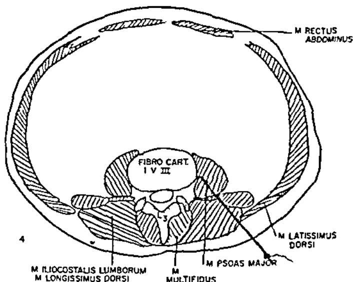



*Figure 1 Schematic drawing of the approach to the psoas muscle*




*Figure 2 Roentgenograms of the electrode in position*

4 Forward leaning 20 degrees and holding 10 kg in each hand
5 Standing upright at ease
6 Standing upright 10 kg in each hand
7 Standing and forward leaning 20 degree
8 Standing and forward leaning 20 degrees 10 kg in each hand
9 Standing on left leg with right leg in abduction

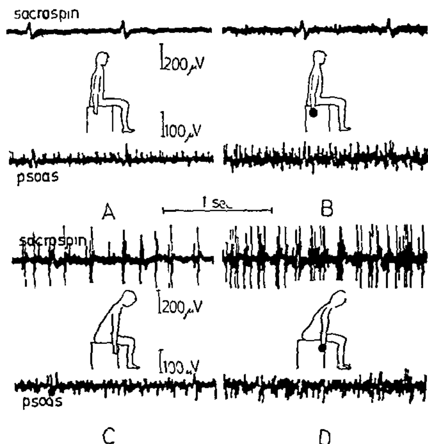



*Figure 3. The electromyographic activity of the vertebral portion of the psoas major muscle, right side, in a male age 25 y.*

*A. Upright unsupported sitting.*
*B. Upright unsupported sitting, 10 kg in each hand.*
*C. Sitting and forward leaning twenty degrees by flexion in the hip joints.*
*D. Sitting and forward leaning twenty degrees by flexion in the hip joints and holding 10 kg in each hand.*

10. Standing on left leg with right leg in adduction.
11. Standing on right leg only.
12. Standing on left leg with maximal flexion and adduction of the right hip.

The four last mentioned tests were also performed to investigate whether the vertebral portion of the psoas takes any active part in abduction or adduction of the hip, a matter of discussion in the literature (6, 13, 16).

One subject was measured twice with one weeks interval. The result from the two tests were identical.

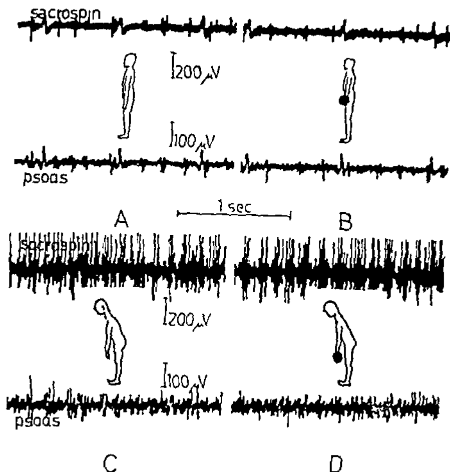



*Figure 4 The electromyographic activity of the vertebral portion of the psoas major muscle right side in a male age 2[illegible] y*

*A Upright standing at ease*
*B Upright standing 10 kg in each hand*
*C Standing and forward leaning twenty degrees by flexion in the hip joints*
*D Standing and forward leaning twenty degrees by flexion in the hip joints and holding 10 kg in each hand*

## RESULTS

*Position 1* Upright sitting without support In all eight subjects a somewhat varying amount of muscle action potentials could be recorded while from the sacro spinalis no activity could be read off from seven and slight activity in one The psoas activity was always greater The same holds for

*Position 2* when 10 kg were added to each hand In this position

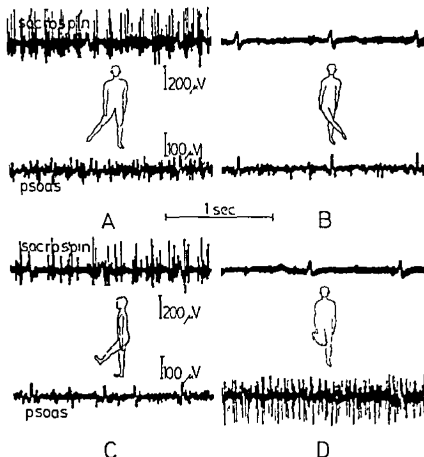



*Figure 5 The electromyographic activity of the vertebral portion of the psoas major muscle right side in a male age [illegible]5 y*

*A Standing on left leg with right leg abducted*
*B Standing on left leg with right leg adducted*
*C Standing on right leg alone*
*D Standing on left leg with right hip flexed and adducted*

however four individuals out of eight showed increased activity in the sacro-spinalis group of the muscles (Figure 3 A and B)

*Position 3* Sitting and forward leaning 20 degrees The psoas activity decreased from positions 1 and 2 in all eight subjects The sacro-spinalis activity increased markedly in all subjects as compared to the previous position With loads added *Position 4* there was increase in both the psoas and the sacro-spinalis activity Still the psoas

activity in Position 1 was greater than in Position 4 in six out of the eight subjects (Figure 3 C and D Figure 6 A–D)

*Position 5* Standing upright at ease In this position seven of the eight individuals showed activity in the psoas major muscle In the sacro spinalis group of muscles activity was found in five and no activity in three

*Position 6* With weights of 10 kg in each hand some activity in the *psoas muscle was found in all cases and in the sacro-spinalis in six out* of the eight subjects (Figure 4 A and B)

*Position 7* Standing and forward leaning 20 degrees The activity in the psoas muscle increased compared to upright standing in five out of eight It was of about the same magnitude as in upright sitting (Position 1) The activity increased somewhat in four with increasing load but remained the same in four The back muscles were very active and increased to an observed maximum in *Position 8* when weights were added (Figure 4 C and D)

*Position 9 and 10* Standing on left leg right leg in abduction and adduction respectively Activity was found in the psoas muscle in all the cases It was of about the same magnitude as in the upright sitting position When the right leg was abducted three individuals showed less activity in the psoas muscle than when the leg was adducted four showed greater activity and in one individual the activity was the same In the sacro-spinalis group of muscles two patients showed no activity when the leg was out and two patients showed no activity when the leg was in Otherwise the activity was *about the same and moderate in all patients (Figure 5 A and B)*

*Position 11* Standing on the right leg only Only five patients were tested The activity in the psoas muscle was about the same as in the upright sitting position while the activity in the sacro spinalis muscles was about the same as in the sitting and forward leaning position (Position 3) (Figure 5 C)

*Position 12* Left leg stance right hip flexed and adducted In all eight subjects there was no activity in the sacro-spinalis group of the muscles but definite and strong activity in the psoas major muscle (Figure 5 D)

## DISCUSSION

As mentioned in the introduction *Basmajian* (1958) (3) reported definite activity in the upright standing position and he called this part of the iliopsoas muscle an active postural muscle The last

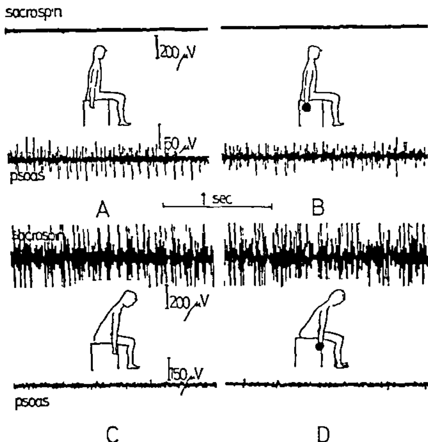



*Figure 6 The electromyographic activity of the vertebral portion of the psoas major muscle, right side, in a male age 30 y*

*A Upright unsupported sitting*
*B Upright unsupported sitting 10 kg in each hand*
*C Sitting and forward leaning twenty degrees by flexion in the hip joints*
*D Sitting and forward leaning twenty degrees by flexion in the hip joints and holding 10 kg in each hand*

*This case clearly demonstrates how the activity in the psoas muscle decreases while the subject leans forward from the upright sitting position, which happened in the majority of the subjects*

mentioned author (3) and *Close* (1964) (6) who studied one subject via the same postero-lateral approach as used by *Basmajan* (3) were mainly interested in the function of muscle upon the hip joint

The results presented suggest that the vertebral portion of the

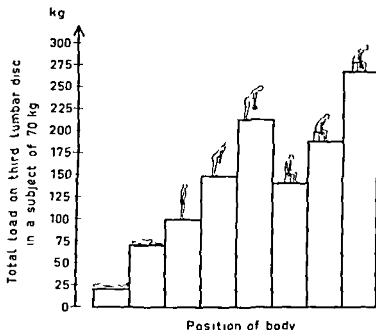



*Figure 7 Approximate load on third lumbar disc in a subject of 70 kg in different positions of body Positions shown are 1) reclining (relaxed supine) 2) reclining (lateral decubitus) 3) standing upright 4) standing + twenty degrees forward leaning without and 5) with 20 kg load in arms 6) sitting upright arms and back unsupported 7) sitting + twenty degrees forward leaning without and 8) with 20 kg load in arms*

psoas muscle may aid in stabilizing the lumbar part of the spine especially in the upright unsupported sitting and the upright standing positions The present finding that there exists electromyographic activity in the psoas in these positions also means that it exerts some force on the lumbar part of the spine

The results obtained from the sacro spinalis group of muscles confirm those of earlier writers (11 12 17 21 22) In the upright sitting position less electromyographic activity at the lumbar level has been demonstrated by *Joseph* (12) and *Schoberth* (22) compared to other portions of the spine

In recordings from the anterior abdominal wall muscles *Floyd & Silver* (1950) (10) could demonstrate that in the standing at ease position there was slight activity in the internal oblique muscle only In most cases no activity was found in the other abdominal muscles nor in the back muscles

*Akerblom* (1949) (24) has shown that in the upright sitting position the lumbar spine is flexed forward In this study the activity in the

psoas muscle when standing and forward leaning 20 degrees was about the same as in the upright sitting position (Figures 3 and 4) On the other hand when the spine is bent forward in the sitting position the psoas becomes less active while the sacro-spinalis group seems to take over (Figure 3 C and D Figure 6 A–D)

In the different positions of one leg stance a variable amount of activity was always found The relation to the hip joint is uncertain By virtue of the psoas activity in the static positions studied it can be concluded however that some compressive force is exerted on the lumbar spine

*Dempster* (1958) (8) stated that whenever the body exerts forces on its environment forming a closed chain system of forces limb and trunk muscles do not directly exert pull forces instead they maintain joint postures which permit body weight to exert an effective moment

It seems that in the lumbar spine the posture in some positions is at least to some extent maintained by the psoas muscle

## SUMMARY

Lumbar disc measurements *in vivo* have in the unsupported upright sitting and upright standing positions revealed that heavier loads rest on the middle lumbar discs than can be explained by gravitational forces alone In these positions the anterior abdominal and the sacro spinalis muscles have been found relatively inactive in previous elec tromyographic studies It has also previously been shown that the ligamentous lumbar spine essentially is an unstable rod which needs external force for stabilization

Electromyography of the right sided psoas major muscle at the level of the third lumbar disc in eight normal subjects four men and four women has shown a varying amount of activity in the upright positions studied In most instances this activity decreased when lean ing forward while the activity of the sacro spinalis group of muscle which were studied simultaneously increased

In standing on left leg with right leg abducted or adducted as well as in standing on right leg activity was also revealed in the psoas

The present investigation seems to support the idea that the verte bral portion of the psoas muscle besides its function as a hip flexor also takes part in maintaining upright postures By its activity it adds a compressive force to the lumbar spine thus adding to the gravitatio nal forces to which the lumbar discs are subjected

## RÉSUMÉ

Des mensurations de la pression de la vertèbre lombaire *in vivo* ont révélé dans la position assise redressée et dans la position debout sans supports qu'une charge plus lourde repose sur les disques lombaires du milieu que celle que l'on peut expliquer uniquement par des forces gravitationnelles. Dans cette position des études électromyographiques ont montré que les muscles abdominal antérieur et sacrospinal étaient relativement inactifs. *Il a aussi été démontré antérieurement que la* colonne lombaire ligamenteuse est essentiellement un fuseau instable qui a besoin d'une force externe pour la stabiliser.

L'électromyographie du côté droit du muscle psoas au niveau de la 3ème vertèbre lombaire chez huit sujets normaux, quatre hommes et quatre femmes, a montré des quantités variables d'activité dans les positions étudiées. Dans la plupart des cas l'activité diminue dans l'inclinaison en avant alors que l'activité du groupe sacro-spinal des muscles étudiés augmente simultanément.

Si l'on se tient debout sur la jambe gauche, la jambe droite en abduction ou en adduction, ou debout sur la jambe droite, activité est aussi *révélée dans le psoas*.

La présente enquête semble soutenir l'idée que la portion vertébrale du muscle psoas, à côté de sa fonction comme fléchisseur de la hanche, participe aussi au maintien de la position verticale. Par son activité il ajoute une force compressive dans la colonne lombaire qui s'ajoute aux forces gravitationnelles auxquelles sont soumises les vertèbres lombaires.

## ZUSAMMENFASSUNG

Druckmessungen an lumbalen disci intervertebrales *in vivo* bei nicht *unterstützter aufrecht sitzender und aufrecht stehender* Stellung haben gezeigt, dass eine grössere Belastung auf den mittleren Lendenscheiben ruht als dies durch Schwergewichtskräfte allein erklärt werden kann. In vorhergehenden elektromyographischen Untersuchungen verhielten sich die vorderen Abdominal- und die Sacro-spinalmuskeln relativ inaktiv. Es wurde auch früher gezeigt, dass die ligamentöse Lendenwirbelsäule im wesentlichen ein unstabiler Stab ist, der zur Stabilisierung äusserer Kräfte bedarf.

Elektromyographie des rechtseitigen m. psoas major in der Höhe des dritten lumbalen Diskus in acht normalen Personen, vier Männern und vier Frauen, hat einen verschiedenen Grad von Aktivität in den

untersuchten aufrechten Positionen gezeigt In den meisten Fällen nahm diese Aktivitet bei vorwarts Beugung ab wahrend die Aktivitet der sacro-spinalen Muskelgruppe die gleichzeitig studiert wurde zu nahm

Beim Stehen auf dem linken Bein mit dem rechten Bein in Ab oder Adduktion oder umgekehrt auf dem rechten Bein wurde ebenfalls Aktivitet in Psoas gefunden

Die vorliegende Untersuchung scheint die Annahme zu unterstutzen dass der vertebrale Teil des m psoas abgesehen von der Funktion als Huftbeuger auch an der Erhaltung der aufrechten Stellung teilnimmt Durch seine Aktivitet fugt er eine komprimierende Kraft auf die Lendenwirbelsäule hinzu und erhoht in dieser Weise die Schwergewichtskräfte denen die Lendenzwischenwirbelsheiben ausgestzt sind

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# GIANT CELL TUMOUR OF THORACIC VERTEBRA

*Case Report*

*By*

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True giant cell tumours of bone in subjects of considerable age are rare and in bones other than long bones very rare The terminology in the literature concerning giant cell tumours of vertebrae is sometimes confusing when no distinction is made between true giant cell tumours on the one hand and aneurysmal bone cysts and benign osteoblastomas (Jaffe) on the other It is important to distinguish between these three conditions as they have a different behavior in the long run as has been pointed out in a recent report by *Cohen et al* (3) The rarity of true giant cell tumours of the vertebral column especially above the sacrum has been pointed out in several publications (3–10) We now report and discuss a case in a woman of 67 years

## CASE REPORT

The patient was a woman aged 67 years the inmate of a mental hospital owing to depression and paranoid delusions She had not previously had any somatic illness of note At the age of 66 years she started to complain of weakness and pain of the back X ray examination revealed compression of the 8th thoracic vertebra to half its normal height The adjacent disks appeared intact X ray examination 6 years earlier had shown a normal thoracic spine About 6 months after the appearance of symptoms she suddenly developed total paralysis of both legs and extreme muscular weakness of the lower trunk Pain sensibility was diminished up to a level 4 inches above the umbilicus The patellar and achilles reflexes were increased and Babinski s response was positive on both sides Serum values of calcium phosphate and alkalin phosphatases were within normal limits At operation a fairly soft "liverlike" tumour was found in the body and arches of the diseased thoracic vertebra

The patient developed left pneumothorax with respiratory distress and wound infection She deteriorated bronchopneumonia followed and she died 3 weeks after operation



*Figure 1 X ray picture of the compressed eighth thoracic vertebra*

At necropsy the eighth thoracic vertebra was found to be destroyed and compressed with remnants of soft liverlike tumour tissue No other skeletal changes could be detected Four parathyroids were found They were not enlarged and histologically normal There were left sided pneumothorax total atelactasis of the left lung and bronchopneumonia

THE TUMOUR

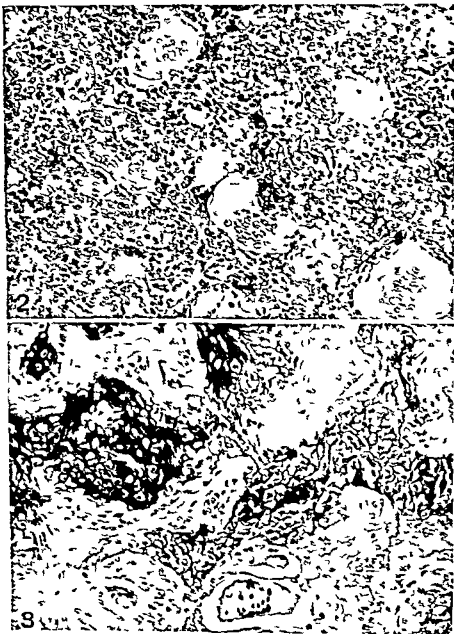
The X ray appearance before operation is seen in Figure 1 Macroscopically the remnants of the tumour had a liverlike reddish cut surface The tumour had not penetrated into adjacent soft tissues

Microscopically there was proliferation of oval to spindle shaped cells with rounded or slightly elongated palish nuclei in a highly vascular stroma (Figure 2) with a large number of multinucleated giant

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*Figure 2 Diagnostic area from the lateral part of the tumour with characteristic picture with vascular stroma proliferation of oval to spindle shaped cells and several giant cells with nuclei similar to those of the spindle cells*
*van Gieson × 130*

*Figure 3 Osteoid tissue in peripheral area of the tumour Note giant cells attached to endothelial lining Van Gieson × 1 5*


2
3

cells throughout the stroma In the periphery of the tumour there was *collagenization and osteoid formation (Figure 3)* There were occasional mitoses The giant cells with centrally situated nuclei were fairly often situated within the capillary lumina and sometimes they seemed to be attached to the endothelial lining (Figure 3)

## DISCUSSION

Although the histological picture of a true giant cell tumour is said to be characteristic several authors (3 4 11 12) maintain that the findings may occasionally be similar in other bone diseases

Except giant cell tumours aneurysmal bone cysts and benign osteoblastoma there are a large number of unrelated lesions of bone that contain multinucleated giant cells Such lesions are brown tumour of *hyperparathyroidism osteogenic sarcoma inflammatory or non specific degenerative processes* chondroblastoma *non osteogenic fibroma* and histiocytosis X

As has been stressed by *Dahlin et al* (13) the problem of accurate *diagnosis is simplified if one disregards the giant cells and instead* observes the stromal pattern and the proliferating cells in the best preserved portions of the tumour

*The problem in the present case is to identify the tumour is a true* giant cell tumour distinguishable from aneurysmal bone cyst and benign osteoblastoma—and from the so called brown tumour of hyperparathyroidism The other of the above mentioned lesions do not have much in common with the present case except multinucleated giant cells

The roentgenological picture is relatively unspecific and is of little help from the point of view of differential diagnosis The secondary compression of the vertebra has undoubtedly also changed greatly the original appearance of the lesion The picture could fit in with a malignant process of primary or secondary nature and also with most of the diagnoses mentioned above

The brown tumour of hyperparathyroidism can histologically be difficult to differentiate from giant cell tumour but in hyperparathyroidism the determination of blood calcium is much more important than histological examination All relevant values were normal in this case which with a considerable degree of certainty excludes hyper*parathyroidism*

The aneurysmal bone cyst (1) is a benign fibrocystic tumour of

bone made up of dilated blood filled spaces These blood filled spaces very often lack a true endothelial lining Giant cells are present in varying numbers In contrast to the well preserved diagnostic portions of true giant cell tumours there are in aneurysmal bone cysts varying amounts of intercellular collagen and osteoid trabeculae in the cellular parts of the cysts In the present case there were no blood filled spaces and collagenization and osteoid formation were noted only in the peripheral parts of the tumour It is probable that the osteoid reaction is at least in part a sequel of the compression fracture (Figures 1 and 3)

The benign osteoblastoma (Synonyms giant osteoid osteoma (2) and osteogenic fibroma) is a benign primary bone tumour composed of varying amounts of trabeculae of more or less calcified osteoid in a well vascularized osteoblastic connective tissue stroma The histological features of this tumour vary markedly even within a single lesion However all these tumours are characterized by active osteoid formation in a loose highly vascular stroma which is rich in osteoblasts Furthermore highly cellular areas of spindle cells in interlacing bundles are uncommon histological features of benign osteoblastoma Giant cells are not a necessary feature of the tumour As has been underlined above there were small areas of osteoid formation only in the peripheral parts of the present lesion The stromal pattern was characterized by vascularity Proliferation of oval to spindleshaped cells was marked in the diagnostic portions of the tumour (Figures 2 and 3)

Mainly on macro- and microscopical findings we have thus settled on the diagnosis of true giant cell tumour There is also a statistical support to the assumption that the present lesion is a true giant cell tumour To the best of our knowledge no convincing case of aneurysmal bone cyst or benign osteoblastoma has been reported in persons more than 35 years old whereas true giant cell tumours are evenly distributed through the ages after the age of 20 years

## SUMMARY

The case is reported of a 67 year old woman with tumour of a thoracic vertebra with compression fracture The tumour is classified on histological grounds as a true giant cell tumour The differential diagnosis is discussed

## RESUME

Il est rapporté le cas d une femme agée de 67 ans ayant une tumeur d une vertèbre thoracique avec fracture de compression La tumeur est classifiée sur la base des données histologiques comme une véritable tumeur de cellules géantes Discussion du diagnostic différentiel

## ZUSAMMENFASSUNG

Der fall eines 67 jährigen weiblichen Patients mit einem Tumor eines Brustwirbels und Kompressionsbruch wird berichtet Histologisch wird der Tumor als ein echter Riesenzellentumor bezeichnet Die Differentialdiagnose wird besprochen


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# A MODIFIED TECHNIQUE FOR PELVIC RECONSTRUCTION IN THE TREATMENT OF EXSTROPHY OF THE BLADDER

*By*

G. GROTTE and J. A. SEVASTIKOGLOU

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Exstrophy of the bladder is a relatively rare congenital malformation occurring once in every 30 000 to 50 000 births (*Higgins* 1959, *Campbell* 1961, *Sorrentino & Leonelli* 1958, *Swenson et al.* 1963). Apart from the pure urogenital malformation this condition is also combined with a severe derangement of the pelvic ring. Diastasis of the symphysis pubis often surpassing 10 cm, posterolateral displacement of the acetabula with a pronounced external rotation and restricted internal rotation of the legs result often in instability of the gait in the growing child (*O'Phelan* 1963).

Until recently the treatment of this condition was directed towards the surgical reconstruction of the urogenital deformity with, as a rule, very poor results. As early as 1906 Trendelenburg performed a combined reconstruction of the pelvic and the urogenital deformity by separation of the sacroiliac synchondrosis in order to obtain approximation of the pubic bones before the reconstruction of the bladder. The method was, however, abandoned because of technical difficulties and the poor results obtained. *Nixon* 1957 by manual osteoclasis of the pelvis obtained successful closure of the bladder in two newborn babies. *Schultz* (1958) and Swartzman were the first to use a bilateral parasacral osteotomy of ilium to secure better possibilities for the approximation of the pelvic bones and hence improvement of the urogenital reconstruction. Since then the combined reconstructive procedure has been used by several authors and very enthusiastic results have been reported during recent years (*Schultz* 1958, *Lloyd Roberts et al.* 1959, *Johansson* 1963, *O'Phelan* 1964). The operative

technique used by these authors consists of bilateral osteotomy of the ilium during a first stage and the reconstruction of the urogenital and symphyseal deformity in a second stage usually one to two weeks after the first In the reported cases the approximation of the symphysis has been secured either by the ilium osteotomies alone and the subsequent compression of the pelvis by a spica plaster cast or splints or by internal fixation of the pubic rami with a wire loop or a strip of fascia lata applied through the obturator foramina during the second stage of the reconstruction Better results regarding the approximation of the symphysis are secured by this fixation In several cases however failure to maintain a lasting approximation of the pelvis bones has been reported Recurrence of the diastasis and erosion of the urethra have been reported in some of the cases

In four cases of exstrophy of the bladder operated upon by us a *somewhat modified technique has been used for the maintenance of* the approximation of the symphysis The reconstructive procedure used in these cases and the results obtained in two of them are reported herewith

## THE RECONSTRUCTIVE PROCEDURE

The reconstructive procedure comprises 3 separate operations performed in two stages At the first stage a bilateral parasacral osteotomy is made One to two weeks later the urogenital reconstruction and the fixation of the symphysis pubis are performed during the second stage

### *First Stage*

#### *Bilateral Parasacral Osteotomy of the Ilium*

Under general anaesthesia and intubation the child is placed prone on the frame for the lumbar spine surgery In this position the *posterior limits of the pelvis are prominent* and easily recognised The *skin incision starts parallel to the posterior iliac crest* and is directed to the superior limit of the sacroiliac joint where it swings caudally parallel to it The attachment of the gluteus maximus muscle is mobilized and retracted laterally so that the parasacral portion of the ilium is freed from the crest down to the greater sciatic notch *Through an* incision on the fascia lumbodorsalis on the crest a finger is passed and the ventral surface of the ilium is freed bluntly near the sacroiliac joint in the caudal direction In the same way dissection is performed

from the greater sciatic notch cranially Two retractors are then pushed gently along the ventral surface of the ilium to meet each other and to protect the underlying tissues during the osteotomy Division of the ilium is performed by a Stryker s saw 1 to 2 cm lateral to the sacroiliac joint and parallel to it When the osteotomy has been accomplished the ilium is mobilized and moved laterally The sacrotuberous ligament is then stretched preventing complete diastasis within the caudal part of the osteotomy When strethed the ligament is easily recognized and divided as advocated by Lloyd Roberts et al Satisfactory diastasis within the osteotomy of 1–1½ cm is then easily obtained Before closing the wound a bone strip 0 5 cm broad is removed from the iliac bone at the site of the osteotomy on each side with the electric saw Under sterile conditions it is preserved in a jar and deep freezed to be used as transplantation material for the reconstruction of the symphysis pubis When the procedure has been accomplished on both sides and the wounds are closed the iliac bones are compressed gently to each other and then immobilized under slight pressure with broad strips of elastoplast dressing

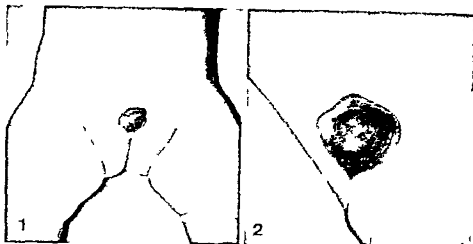
## *Second Stage*

### 1 *The Urogenital Reconstruction*

A horseshoe shaped incision is made around the bladder except along the urethra The bladder is extensively mobilised posteriorly down to the trigonum The intersymphyseal band is detached from the pubic tubercles by subperiostal dissection After adequate mobilisation the bladder and urethra are carefully reconstructed over a no 12 Malecot catheter The reconstruction is made in two layers using 3-0 chromic catgut sutures The intersymphyseal band is coapted like a collar around the bladder neck Improvements of this technique using suprapubic sump drainage and pressure studies during the reconstruction of the bladder neck have been suggested by *Swenson et al* (1963) but were not used in the present cases The incisions mobilizing the bladder and the bladder neck and especially reconstruction of the bladder under dissection microscopy (Leitz operation microscope) greatly facilitate the procedure

### 2 *The Fixation of the Symphysis*

When the reconstruction of the urogenital deformity has been accomplished the medial aspects of the pubic bones are freed by blunt



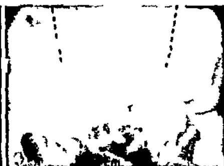

*Figures 1 and 2 Case No 1 The bladder exstrophy at birth*

dissection down to the obturator foramina through the same skin incision A stainless steel wire is passed around the rami of pars pubica of the sciatic bones which are pushed together to complete approximation before the wire loop is tightened An incision is then made on the upper surface of the cartilaginous pubic parts until the ossified central region of the bones is revealed The bone fragments removed during the first stage from the site of the iliac osteotomy and kept in the deep freezer are thawed and inserted within the prepared cartilaginous cleft to reach contact with the ossification centre of the bone An amount of bone chips is packed around the bone graft After closure of the wound a spica plaster cast is applied with the iliac bones under slight pressure to each other and the legs kept in a neutral position and in slight abduction After 4–6 weeks the plaster cast is removed and immobilization continues for another 2–4 weeks by means of a splint as advocated by *Sweetser* (1960) At this time the iliac osteotomies are usually healed and the child is allowed out of bed

## CASE REPORTS AND RESULTS

*Case 1* The first case concerns a female baby the only child in the family born after a full term pregnancy with an urogenital deformity No other congenital malformation No heredity of congenital abnormalities She was admitted to the department of pediatric surgery from another hospital 3 weeks after partus At the time of admission the urogenital deformity consisted of a complete epispadias and exstrophy of the bladder (Figures 1 and 2) I v pyelography showed no anomalies of the kidneys and the upper urinary tract No pathological urine flora The orth-



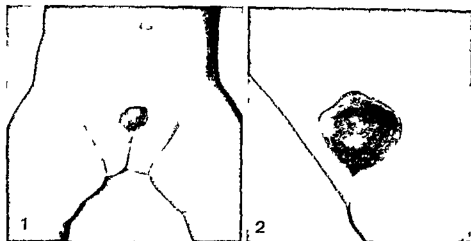




*Figures 3, 4 and 5. Case No. 1. 3. The initial X-ray of the pelvis develops a 4.2 cm diastasis between the osseous parts of the pubic bones. 4. Slight decrease of the diastasis immediately after bilateral iliac osteotomy. 5. After reconstruction of the symphysis and fixation of the pubic bones with a wire loop the diastasis decreased to 1.4 cm. The transplanted bone is not visible at the X-ray.*

pacific examination revealed a diastasis of the symphysis of at least 4 cms confirmed also by X-ray (Figure 3). In a lying position the patient keeps her legs slightly abducted. There is, however, a normal stability and range of motion within both hip joints. The Ortolani test is bilaterally negative. The girl started to walk at the age of 13 months with apparently normal gait for this age. When standing up the legs are kept slightly abducted but there is still normal range of motion and normal stability within both hips. There was a slight low leg deformity at the time of surgery. The girl was operated upon at the age of 1 year 4 months. Bilateral iliac osteotomy was performed first (Figure 4) and 12 days later surgery for reconstruction of the urogenital deformity and the symphysis followed (Figure 5) according to the described technique. The pelvis and the legs were immobilised with a plaster cast for 6 weeks and later with a special splint for another 4 weeks. She started to walk again as soon as the splint was removed. She now keeps her legs in midposition when standing up. The Trendelenburg sign is negative bilaterally.

Because of erosion of the wire loop through the pubic bones and through the anterior wall of the urethra the wire was removed 9½ months after the reconstruction of the symphysis. At the latest follow up examination 16 months after surgery the girl is 2 years 8 months old. She grows normally. She walks and runs uninhibitedly. The gait is normal. The operation scars are well healed (Figures 6 and 7) with no tenderness at palpation. The pubic bones are well approximated and a bony continuity is felt overlapping the symphysis. There is no leg length discrepancy. The pelvis is horizontal with no deviation of the spine. She keeps her legs in normal midposition when standing up. There is normal range of motion within both hips. The low leg deformity has disappeared. There is only a moderate flat foot deformity



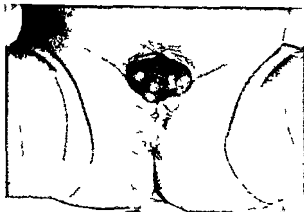

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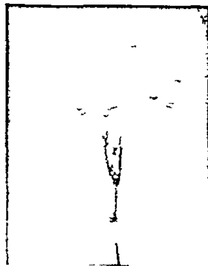
## CASE REPORTS AND RESULTS

*Case 1* The first case concerns a female baby, the only child in the family, born after a full term pregnancy with an urogenital deformity. No other congenital malformations. No heredity of congenital abnormalities. She was admitted to the department of pediatric surgery from another hospital 3 weeks after partus. At the time of admission the urogenital deformity consisted of a complete epispadias and exstrophy of the bladder (Figures 1 and 2). I v pyelography showed no anomalies of the kidneys and the upper urinary tract. No pathologic urine flora. The ortho-

*Case 2* This case concerns also a female infant the second child in a family with 2 children No heredity of congenital abnormalities She was born after a full term pregnancy with a severe exstrophy of the bladder (Figure 9) No other congenital malformations are present No orthopaedic examination was performed immediately after birth At the age of 2 months the girl was admitted to the Department of Plastic Surgery where reconstruction of the bladder the bladder neck and the urethra was performed The procedure resulted in a successful closure (Figure 10) The urinary incontinence was however unaffected Except for several attacks of pyelonephritis the girl developed severe difficulties with micturition i e pain and retention for which catherization of the bladder was necessary on several occasions The patient was admitted to the Department of Pediatric Surgery at the age of 3 years 4 months A bladder stone was diagnosed and removed Stricture of the bladder neck was assumed to be the reason of her retentions and since catherization

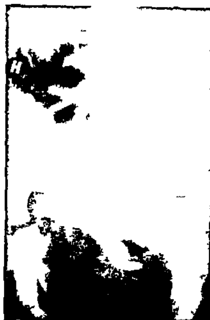


9



10

*Figures 9 and 10 Case No 2 9 The bladder exstrophy at birth 10 A successful closure of the abdominal wall has been obtained after the first reconstruction operation*



*Figures 11 Case No 2 The initial X ray of the pelvis shows a 6 cm diastasis between the osseous parts of the pubic bones*



*Figures 12 Case No 2 Immediately after iliac osteotomies the diastasis decreased to 4 cms*

and dilatation failed to give any result it was therefore decided to operate on her again The first orthopaedic examination revealed a well developed 4 year old girl She started to walk at the age of 1 year 4 months No remark was found on the records of any early static or walking disorder The gait is stable and normal There is no pathologic finding from the hips No abnormal posture of the legs exists when standing There is a diastasis of the pubic bones of almost ... cm The pelvis and the spine look normal X ray examination of the pelvic girdle shows a diastasis of the pubic bones of 6 cm (Figure 11) Bilateral iliac osteotomy was performed at

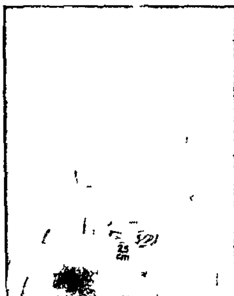



*Figure 13. Case No. 2. Reconstruction of the symphysis and fixation of the pubic bones by a wire loop decreased the diastasis to 25 cms. Note the bone transplant over the symphysis.*




*Figure 14. Case No. 2. Two months after the removal of the wire loop the distance between the osseous parts of the pubic bones is still unchanged. The transplant is not visible longer. No signs of osteogenesis at the site of transplantation.*

the age of 4 years 2 months (Figure 12). Eight days later a reconstruction of the symphysis was performed (Figure 13) and at the same time resection of scar tissue around the bladder and the bladder neck was performed. A good mobilization of the bladder was then obtained and its reposition in the pelvis became possible. The abdominal wall was easily reconstructed. The pelvis and the legs were immobilized by a plaster cast for 10 weeks and by a splint for another 4 weeks. Thereafter the girl was up and moved freely within a few days. The wire loop was removed 5½ months later (Figure 14), since it had eroded through the pubic bones and the anterior wall of the urethra.

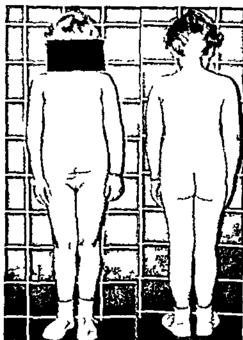


*Figure 15* *Figure 16*

*Figures 15 and 16 Case No 9 at follow up examination 3 years 6 months after the operation 15 the scars after the iliac osteotomies are visible 16 The slight outward rotation of the right leg is occasional*

At the last follow up examination 3 years 6 months after surgery the girl is 7 years 8 months old and she has developed in a normal way She walks and runs freely The gait is normal The operation scars are well healed (Figures 15 16 and 17) with no tenderness on palpation The pubic bones are felt well approximated and there is a bony continuity overlapping the symphysis Normal range of motion exists within both hips There is no leg length discrepancy The legs are in the midposition when standing up Somewhat increased lumbar lordosis The pelvis is horizontal There are no pathologic deviations of the spine On X ray examination the iliac osteotomies were completely healed The diastasis between the osseous parts of the pubic bones has remained unchanged since the operation (Figure 18) The transplanted bone in the symphysis is not visible on the X ray and there are no signs of osteogenesis at this place either The urogenital condition is more or less unchanged There is still a complete incontinence of the bladder The girl had had several attacks of pyelonephritis after the operation as well but n pain at micturition and no residual urine The i v pyelography reveals a slight dilatation of both kidney pelvis and ureters

## DISCUSSION

The treatment of the exstrophy of the bladder has always been one of the major problems in surgery Different methods of reconstructing the urogenital deformity gave but very poor results primarily because of

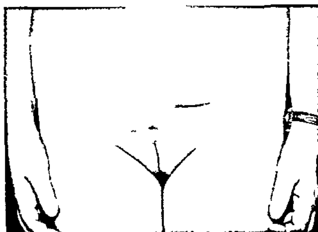


*Figure 17 Case No 9 at followup examination 3 years 6 months after the operation — The scars after the abdominal surgery are well healed*



*Figure 18 Case No 2 X ray of the pelvis 3 6/12 years after the operation The diastasis between the pubic bones is still unchanged There is no bony uniform at the place of bone transplantation*

the failure to close the symphysial gap which is the key to success in treating this condition (*Matthews* 1958) Iliac osteotomy and approximation of the symphysis increased considerably the possibilities of successful reconstruction of this extremely severe malformation The chief virtue of the pelvic reconstruction is the fact that the soft tissues are brought more closely together and thus make it possible that urinary control may be better at a later date There is no necessity for skeletal reconstruction since the posture and moving activities in older cases with no reconstruction of the pelvis have been reported to be fairly normal (*Lattimer et al* 1960) Since the introduction of the

*Table 1*

| Author | No of cases | Partial obstruction or erosion of the urethra by the wire |
|---|---|---|
| Schultz (1958) | 1 | No complication reported |
| Lloyd Roberts & Braddock (1959) | 7 | No wire fixation of the symphysis was used |
| Lattimer et al (1960) | 4 | In all the cases |
| Chisholm (1961) | 12 | In 10 cases |
| Johanson et al (1962) | 4 | No complications reported |
| O Phelan (1963) | 24 | In all the cases |

combined procedure by *Schultz* (1958) reports have been published by different authors who obtained very encouraging results by using this method However because of the rarity of the condition the reported series comprise relatively small number of cases (Table 1) and the experience gained until now can by no means be considered as definite A common complication in the reported cases treated by either iliac osteotomy alone or combined with approximation and fixation of the symphysis by wire or fascia lata is an increasing diastasis of the symphysis after the removal of the plaster cast and the compression of the pelvis Erosion of the wire loop through the pubic bones is very common and it is followed by loosening of the primarily obtained approximation of the symphysis Displacement of the wire includes the risk of a partial or complete obstruction of the urethra and the loop must therefore be removed as soon as signs of erosion of the pubic bones are present in the x ray examination Removal of the wire is also recommended as soon as the iliac osteotomy is healed and the child is allowed up (*O Phelan* 1963) Erosion of the wire through the bones and its removal are always followed by a relapse of the diastasis of the pubic bones resulting in tension on the bladder neck and the urethra which might influence bladder continence This complication is usually the reason for the failure of the urogenital reconstruction (*Trendelenburg* 1906) To overcome this complication bone transplantation has been used by the authors in addition to the wiring of the pubic bones In the reported two cases no relapse of the diastasis occurred although the wire had to be removed approximately 9½ months after the operation in the first case In the second case the wire was removed 5½ months after the operation and there is no increase of the diastasis 3 years 6 months

after the operation either[1] The maintenance of the approximation obtained primarily is apparently due to the bone transplantation A bony bridge overlapping the symphysis was felt at the clinical examination of the patients and although not visible in the x rays it keeps the pubic bones in close approximation

It was suggested earlier that reconstructive surgery for exstrophy of the bladder must be undertaken preferably at the age of about one year In the reported cases the best results were obtained when the patients were operated earlier and surgery immediately after birth gave in one case satisfactory primary results

## SUMMARY

A modified technique for pelvic reconstruction in the treatment of exstrophy of the bladder has been used by the authors in 4 cases The use of bone transplantation for the stabilisation of the approximated pubic bones during the reconstruction of the symphysis gave in every case good primary results with no relapse of the pubic diastasis although the used wire loop was removed shortly after the operation Two of the cases with a follow up of 1 year 4 months and 3 years 6 months respectively are reported

## RESUME

Une technique modifiee de reconstruction pelvienne dans le traitement d une exstrophie de la vessie a ete utilisee par les auteurs dans 4 cas l utilisation de transplantation osseuse pour la stabilisation des os pubis pendant la reconstruction de la symphyse a donne dans chaque cas de bons resultats primaires sans relachement de la diastase pubienne bien que la bride utilisee ait ete retiree peu apres l operation Deux cas suivis pendant un an un tiers et 3 ans et demi respectivement sont rapportes

## ZUSAMMENFASSUNG

Eine abgeanderte Technik zur Bekkenrekonstruktion bei der Behandlung der extrophischen Blase wurde von den Verfassern in 4 Fallen

[1] Another two cases were recently operated on by the authors one of which concerned a 3 day old female baby In both cases a teflon arterial prosthesis 5 mm in diameter was used for the fixation of the reconstructed symphysis instead of a wire loop In both cases because of an extensive local reaction and suppuration the fixation material was removed shortly after the operation No loosening of the primarily obtained approximation has been observed 2 3 months later

angewendet Die Verwendung von Knochentransplantaten zur Stabilisierung der angenaherten ossa pubica während der Rekonstruktion der Symphyse gab in jedem Falle gute primare Resultate ohne Ruckfall der pubischen Diastase obwohl die verwendete Drahtschlinge bald nach der Operation entfernt wurde Über zwei Fälle mit einer Beobachtungszeit von 1 4/12 beziehungsweise 3 6/12 Jahren wird berichtet

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# THE EFFECT OF AN ANTIMICROBIAL COATING ON METAL IMPLANTS

## *A Pilot Study in Goats*

*By*

A G Towers and N L Stinson

Received 17 x 65

Reconstructive surgery in which implants are used is an ever widening sphere in which the techniques demand highly integrated team work with considerable emphasis on the prevention of wound infection It is well recognised that factors influencing sepsis are increasing age of the patient the presence of a foreign body the exposure of tissues for long periods of time and the inability to use no touch techniques These factors operate when complicated procedures involving massive prosthetic replacements are undertaken Implants separate the tissues and many of the prostheses used have cavities where bacteria can proliferate remote from attack via the blood stream

There is a divergence of opinion concerning the value of locally applied antibacterial agents especially when used in the presence of metal implants No assessment of the use of these agents could be found in the literature This investigation was undertaken to try and establish the value of a known bactericidal agent when carried in a vehicle with which implants could be coated To be effective the agent should be slowly released at the site Infection was deliberately introduced at the time of operation in the goats which were the animals used in this pilot study

Polyvinyl alcohol was chosen as the most suitable vehicle for the following reasons

(1) It is relatively inert in the body and has been used in the various forms in surgical procedures in both laboratory animals and man since 1951

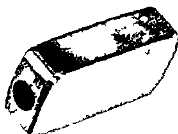


*Figure 1*
*Cobalt chrome alloy implant*

(2) It does not react with any of the known antimicrobial agents
(3) It can be sterilised by autoclaving
(4) It has flow characteristics such that it will penetrate small cavities and dries leaving a non tacky intact continuous coating on the surface of the component
(5) The dry sterilised film is firmly adherent to the metal and does not flake or peel It is strong enough to withstand the manipulations of surgical implantation
(6) It is not absorbed from the metal surface even after five months implantation

It was used as an aqueous solution of solvent for the stable di iso ethionate salt of dibromopropamidine (D B P A) D B P A has been shown to have a marked inhibitory action towards pyogenic cocci but in strengths of 1 5 per cent it had some toxicity towards leucocytes (1–5)

Laboratory tests showed that 0 1 per cent D B P A in PVA dried as a film on test implants of cobalt chrome alloy[1] exhibited a marked inhibitory action towards staphylococcus pyogenes This action was retained for three to four days as shown by successive transplants of the metal on freshly inoculated plates Autoclaving for a second time after two weeks did not appreciably diminish the activity of the D B P A and after six days in goat plasma at 37 C the coated implant still showed a minimal zone of inhibition (see Figures 1 2 and 3)

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1 Composition of the alloy conformed with that specified in B S 3 31 1962 for cast cobalt chrome alloy

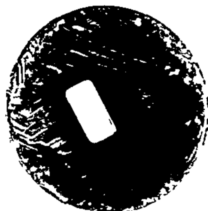


*Figure 2 To show effect of alloy coated with 0.1 per cent DBPA in PVA on G 17 staphylococcus*

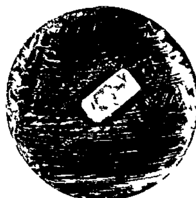


*Figure 3 To show inhibitory zone after 4th transfer of coated implant*

## METHODS AND MATERIALS

*Experimental Plan*

Twelve drilled blocks of cobalt chrome alloy were inserted in the paravertebral muscles of each of six month old Saanen goats The metal implants were classified into the following groups —

(1) Metal alone with and without G 17 staphylococcus

(2) Metal coated with PVA without G 17 staphylococcus

(3) Metal coated with PVA and 0.1 per cent DBPA with and without test doses varying from 10–1 million organisms of G 17 staphylococcu

(4) Metal coated with PVA and 1.0 per cent DBPA with and without test doses varying from 50–100 organisms of G 17 staphylococcus

Implants from more than one group were implanted into each of the six goats and the implantation times varied from six weeks to six months (see Table 1)

*Goats*

The female Saanen stock goats were obtained from the Agricultural Research Council Compton near Reading Berks

*Implants*

Cobalt-chrome alloy blocks measuring 2 mm × 6 mm × 11 mm were used with a cavity 3 mm in diameter drilled mm in length (see Figure 1) These were prepared for use as follows

The blocks were degreased in trilene left to drain on fat free filter paper for two hours in a refrigerator and stored in degreased glass stoppered jar and then prior to use were washed in 1.18 per cent nitric acid for 20 minutes at 40–60 C, rinsed thoroughly in distilled water and dried

| | Implants without organisms | | | |
|---|---|---|---|---|
| | No of implants | No of goats | Duration of Implantat[ion] | |
| Metal alone | 4 | 4 | 10 weeks<br>5 months<br>6 months | 2 implant[s]<br>1 implant<br>1 implant |
| Metal + Polyvinyl Alcohol | 7 | 2 | 6 weeks<br>4 months | 6 implant[s]<br>1 implant |
| Metal + Polyvinyl Alcohol + 0 1 per cent D B P A | 10 | 2 | 6 weeks<br>4 months | 6 implant[s]<br>4 implant[s] |
| Metal + Polyvinyl Alcohol + 1 per cent D B P A | 2 | 1 | 10 weeks | 2 implant[s] |

The polyvinyl alcohol chosen as the most suitable vehicle was Polyviol W 100 450 mixture No 537 manufactured by Wacker Chemie GmbH It was supplied as an 11 per cent aqueous solution The stable di iso ethionate salt of dibromopropamidine was made up in strengths of 0 1 per cent and 1 0 per cent in the aqueous solution of PVA The resultant solutions were colourless transparent and rather viscous at room temperature They were more easily used at 56 C

The implants were submerged in the viscous field care being taken to ensure the central core was completely filled They were then inverted on thin degreased glass supports and dried in vacuo over P O for 48 hours The implants now had a thin plastic film firmly adherent to the metal and lining the cavity Implants were also prepared having a film of PVA only

All implants were sterilised in a high vacuum steam steriliser for 30 minutes at 136 C care being taken to ensure proper drying took place If this is not done the implants remain tacky and difficult to use without damage to the film

### *Staphylococcus Pyogenes*

A strain G 17 primarily isolated from a goat in whom it had caused severe mastitis was used An 18 hour culture from blood agar was suitably diluted just prior to the goat operation and 0 1 ml was used in the case of each implant Plate count control was made in triplicate from the two lowest doses *i e* 10 and 50 organisms per 0 1 ml and in duplicate from the rest

### *Method of Implantation and Removal*

Insertion and removal of the implants was done with strict aseptic technique with the goats intubated and under general anaesthesia The implants were put into the paravertebral muscles below deep fascia with the core pointing towards the head When organisms were used they were confined to the same side of the mid

| umber of organisms | *Implants with organisms*<br>No of implants | No of goats | Duration of implantation |
|---|---|---|---|
| 0 organism per implant | 2 | 2 | 5 months 1 implant<br>6 months 1 implant |
| done as polyvinyl alcohol not inhibitory to pyogenic cocci | | | |
| 0 10 50 etc<br>rganisms per 0 1 ml | 10 | 3 | 4 months 9 implants<br>6 weeks 1 implant extruded |
| 0 100 1 000<br>rganisms per 0 1 ml | 3 | 1 | 10 weeks 3 implants |

line of the vertebral column so that "clean" side and test dose side was maintained X ray examination was made prior to the removal of the implants as migration of the metal blocks occurred in the muscle planes

Bacteriological examination was made at the time of removal at the site and of the pus when this was present and all the implants were cultured. The capsules found round the implants on removal were examined histologically

## RESULTS

### *Bacteriological*

#### *Metal alone implants coated with PVA PVA + 0 1 per cent D B P A and PVA + 1 0 per cent D B P A No organisms*

The implants migrated frequently from site of insertion all were embedded in smooth lined fibrous capsules containing straw coloured serous fluid with semi solid plugs of clot in the cavity of the metal (see Figure 4) There were no abscesses found at any of these sites and there was no evidence of metastatic spread of infection even to sites containing uncoated metal Swabs taken from these sites and culture of the 23 implants concerned all proved sterile

#### *Metal alone + G 17 Staphylococcus*

A chronic abscess within a thick fibrous capsule surrounded the implants after five and six months Culture of the pus and implants

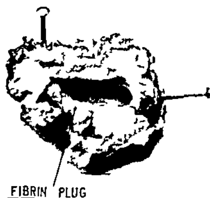



*Figure 4 Thin smooth walled capsules showing plug*



*Figure 5 Chronic Abscess found within thick walled fibrous capsule*

resulted in recovery of an organism undistinguishable from the G 17 staphylococcus (see Figure 5)

*Implants Coated with 0 1 per cent D B P A + Varying Test Doses*

The three implants recovered from sites with 10 10 and 50 organisms per 0 1 ml challenge all proved sterile as were the swabs taken from the smooth capsule These three sites with test organisms did not develop abscesses even after five to six months The remaining seven implants with challenge doses of 50—1 million organisms per 0 1 ml all resulted in typical chronic abscess formation embedding the implants in thick pus and thick fibrous capsules Recovery of the test organism resulted from all seven implants

*Implants Coated with 1 0 per cent D B P A in PVA*

Here the strength of the antibacterial agent was ten times that used previously and the challenge doses with three implants were 50 100

and 1 000 organisms per 0 1 ml Fluctuant abscesses were felt at all three sites after ten weeks Culture of both pus and implant resulted in recovery of a staphylococcus identical with the test organism

### *Histology*

The implants which did not contain organisms were enclosed in relatively thin fibrous tissue capsules in which inflammatory cells were minimal Foamy areas which consisted of foci of macrophages with vacuolated cytoplasm and voids were obvious in the fibrous tissue surrounding the metal blocks coated with PVA alone and with PVA and D B P A

Implants containing 10 organisms were enclosed in mature fibrous tissue capsules in which there was a slight round cell infiltration Implants which contained 50 organisms or more were embedded in a purulent exudate surrounded by organising granulation tissue of considerable depth There was no apparent difference in the histological picture seen around the coated metal blocks and that seen around the uncoated blocks

## CONCLUSIONS

(1) Polyvinyl Alcohol is a useful vehicle for coating surgical implants

(2) The inhibitory action of D B P A towards the test dose of staphylococcus was apparent in one goat only where there was no evidence of infection with up to approximately 50 organisms with three implants coated with 0 1 per cent D B P A However in two other goats with similar test doses of approximately 50 organisms chronic abscesses developed even though one implant had in its film ten times the concentration of D B P A There was no evidence that this higher concentration had had any effect on the prevention of abscess formation

(3) There was no evidence of metastatic spread of abscesses from infected to clean side containing uncoated or coated implants

## RESUME

(1) L alcool polyvinyl est un produit utile pour enduire les implantations chirurgicales

(2) L action inhibitive de l alcool polyvinyl DB par rapport a la dose de staphylococques du test est apparue chez une chevre seulement alors qu il n y eut pratiquement aucun signe d infection dans environ 50 organismes avec trois implantations enduites de 0 1 pour cent d alcool

DBPA Quoi qu il en soit chez deux autres chevres avec des doses de test similaires d environ 50 organismes des abcès chroniques se sont développés bien que l une des implantations ait eu dans son film dix fois la concentration de DBPA Il n a pas ete prouve qu une concentration plus elevee ait un effet quelconque pour prévenir la formation d abces

(3) Il n y a pas de preuve d une propagation metastasique des abces du cote intact contenant des implantations non enduites ou enduites

## ZUSAMMENFASSUNG

(1) Polyvinylalkohol ist ein brauchbares Losemittel zur Uberziehung chirurgischer Einpflanzungen

(2) Die hemmende Wirkung von D B P A auf die Probedose von Staphylococcus zeigte sich nur bei einer Ziege bei der kein Zeichen von Infektion mit bis zu ungefähr 50 Organismen auf drei Einpflanzungen die mit 0 1 Prozent D B P A uberzogen waren nachweissbar war Bei zwei anderen Ziegen jedoch mit ähnlichen Probedosen von ungefähr 50 Organismen entwickelten sich chronische Abscesse obwohl ein Implantat in seinen Überzug die zehnfache Konzentration von D B P A hatte Kein Bewis dass diese hohere Konzentration irgendeine Wirkung auf die Verhinderung von Abscessbildung hat war vorhanden

(3) Keinerlei Beobachtung von metastatischer Ausbreitung von *infizierten zu reinen Stellen die nichtuberzogene oder uberzogene Im*plantate enthielten wurde gemacht

It is a pleasure to thank *May* and *Baker* Limited for their supply of P V A I W 100/450 and of the di iso ethionate salt of Dibromopropamidine

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Acta orthop. Scandinav. 37, 219–228, 1966

From the Clinic for Orthopaedics and Traumatology (Chief: Professor K. E. Kallio) and the Department of Forensic Medicine (Chief: Professor U. Uotila), University of Helsinki

# REGENERATION OF THE FEMORAL HEAD AFTER SUBCAPITAL OSTEOTOMY

## *An Experimental Study on Young Rabbits*

*By*

P. Slätis & P. Rokkanen

Received 1. xii. 65

The changes occurring in the femoral head after severance of the femoral neck are still a subject of much investigation. The incidence of aseptic necrosis of the femoral head depends mainly on the damage to the nutritive vessels in the capsule, the ligamentum teres and the cancellous bone itself. Depletion of the arterial blood supply results in necrosis of the head, occurring in a high percentage of the cases both in man and in experimental animals (for ref. see *Rokkanen* 1962). The subsequent regeneration of the dead bone is a slow process taking place as a creeping substitution (*Phemister* 1926). This regeneration of the necrotic head has frequently been confused with the healing process of the fracture in the femoral neck; these phenomena, although closely related, should be kept apart since they occur at different times, and the fracture repair can take place despite vast necrosis of the femoral head (*Bessler & Müller* 1961, *Sevitt* 1964).

In young rabbits the main nutritive vessels to the femoral head are in the capsule. The importance of the ligamentum teres diminishes with increasing age (*Lemoine* 1957). In young animals the epiphyseal cartilage acts as a barrier between the metaphyseal and epiphyseal vessels (*Harris & Hobson* 1956). A subcapital osteotomy of the femoral neck will thus cleave the head into an upper, epiphyseal part and a lower, metaphyseal part, leaving no communicating blood vessels be-

This work has been partly aided by an institutional grant from the *Sigrid Jusélius Foundation*, Helsinki, to the Department of Forensic Medicine, University of Helsinki.

tween these two areas Experiments during such conditions were expected to give information on the route of regeneration of the avascular femoral head and will be reported below

## MATERIAL AND METHODS

On 25 rabbits 8 weeks of age and of both sexes the left hip joint was exposed through a posterolateral incision The ligamentum teres was severed the femoral head luxated and the femoral neck osteotomized with an electrical saw The free femoral head was replaced in the acetabulum and the wound closed in layers On an additional series of 14 rabbits the same osteotomy of the femoral neck was done leaving the ligamentum teres intact and without luxation of the femoral head No internal or external fixation was used and the animals were allowed to move freely in the cages

The animals were killed 1 2 3 6 12 16 24 and 28 weeks after the operation respectively Both hip joints were dissected free and macroscopically examined The femoral head was radiographed sawed in halves in a frontal plane and embedded in paraffin and methyl metacrylate for further study

*Histological preparations* were decalcified according to the EDTA method and stained by the hematoxylin eosin and the P A S oxidation methods

*Autoradiographs* were made of 12 animals 1 and 3 weeks after the operation using radioactive phosphorus $P^{32}$ administered in a dose of 1 µc/g body weight intraperitoneally 24 hours prior to death The autoradiographs were made on Kodak Autoradiographic Stripping Plates AR 10 the exposure time being 3 weeks

*Oxytetracycline labelling* of the bone was made by giving the animals oxytetracycline 50 mg/kg body weight on three consecutive days prior to death The fluorescence technique of the metacrylate embedded specimens has been described earlier (*Rokkanen & Slatis* 1965)

## RESULTS

One to two weeks after osteotomy a fibrous sheath could be demonstrated in 4/6 specimens arising from the capsule and growing around the femoral neck towards the femoral head to which it adhered Apart from this the femoral head remained unattached to the surrounding tissue Radiographically the head was unaltered Histological signs of aseptic necrosis were as a rule minute and in no case could an undisputable total necrosis of the femoral head be demonstrated The growth cartilage however was affected in all specimens as judged by defective staining and karyolysis Autoradiographs lacked uptake of radioactive phosphorus in 2/3 animals In one animal with a strong soft tissue cuff the metaphyseal part had a slight uptake of radioactive phosphorus The same uptake could be demonstrated by the OTC labelling technique (Figure 1)

Three weeks after the osteotomy the fibrous sheath around the

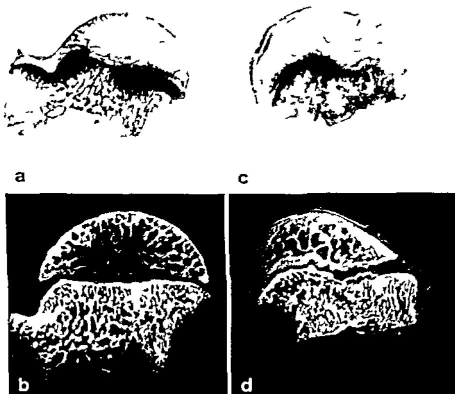



*Figure 1 Autoradiograph (a) and fluorescence micrograph (b) of the right femoral head in a rabbit 8 weeks of age Note the uptake of radioactive phosphorus and fluorescing oxytetracycline in the epiphysis and metaphysis predominantly in the subchondral area In c and d the left femoral neck of the same animal is depicted 1 week after subcapital osteotomy of the femoral neck and severance of the ligamentum teres The epiphysis is devoid of radioactive and fluorescing material In the subchondral area however deposits of radioactive phosphorus and oxytetracycline can be seen*

femoral neck was in most cases encircling the site of fracture like a callous cuff the upper edge adhering to the movable femoral head Still no radiographic changes apart from the fracture line could be demonstrated Histologically the degenerative changes in the metaphysis and to a lesser degree in the epiphysis were now readily demonstrable The first signs of regeneration could be demonstrated in 10 11 animals fibrous tissue invading the metaphyseal part of the femoral head and growing towards the growth plate Autoradiographs revealed

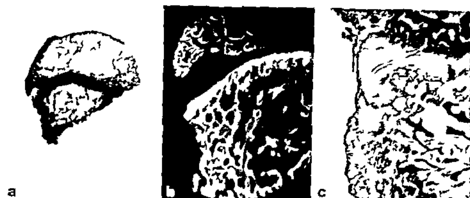



*Figure 2. Autoradiograph (a), fluorescence micrograph (b) and micrograph (c) of the femoral head 3 weeks after subcapital osteotomy of the femoral neck and severance of the ligamentum teres. The uptake of radioactive phosphorus and fluorescing oxytetracycline in the metaphysis and the medial part of the epiphysis is clearly seen. Connective tissue invades the metaphysis and the corresponding medial part of the epiphysis growing from below upwards. The rounded structure of the femoral head is still unaltered.*



*Figure 3. Fluorescence micrograph of the femoral head 1 week after subcapital osteotomy of the femoral neck and severance of the ligd. teres. The epiphysis is devoid of fluorescing material except for a narrow zone beneath the articular cartilage.*

uptake of radioactive material principally in the metaphyseal area but also in some cases in the medial part of the epiphysis. Labelling of the bone with oxytetracycline gave a quite similar uptake pattern. The fluorescing tissue in the specimens corresponded closely to the tissue exerting radioactivity in the autoradiographs (Figure 2). In about half

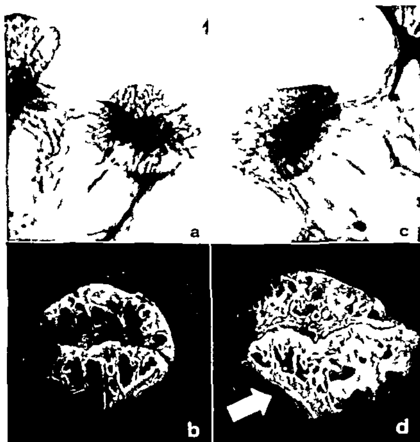



*Figure 4 Radiograph (c) and fluorescence micrograph (d) of the femoral head and neck 20 weeks after subcapital osteotomy of the femoral neck and severance of the ligamentum teres The osteotomy is healed (arrow) leaving a broad femoral neck and a flattened femoral head Note the intense fluorescence in the fracture area as compared with the unoperated side of the same animal (a b)*

of the cases during the first 3 weeks a narrow zone of oxytetracyclin labelling could be demonstrated under the articular cartilage of the avascular femoral head (Figure 3)

At 6 weeks the first radiographic changes occurred In 3 6 animals the femoral head was flattened Histologically these specimens revealed derangement of the trabecular network with narrowing of the marrow spaces and collapse of the weight bearing area of the epiphysis Massive invasion of fibrous tissue in the metaphysis partly extending to the epiphysis and ossification of the growth plate were common observa

tions Oxytetracycline labelling revealed fluorescing areas both in the metaphysis and epiphysis The distribution and intensity of the fluorescence varied however considerably

At 12 weeks the first healed osteotomy was recorded In most specimens *the femoral head* was *flattened* histologically the regeneration was now reaching the epiphysis and in all but one specimen the ossification of the *growth plate had proceeded further than on the* healthy side Fluorescing tissue was found in the femoral head in all cases and this fluorescence was constantly more intense than on the unoperated side This was the case regardless of the degree of healing of the osteotomy

Later 16–28 weeks after the osteotomy 9/10 osteotomies had healed Histologically the regenerative process was completed in 18 cases although intense fluorescence revealed increased activity in several cases (Figure 4)

*Throughout the experiment the degenerative changes* and *the sub*sequent route of regeneration was the same in the group of animals in which the ligamentum teres had been *left intact*

DISCUSSION

Subcapital intra articular osteotomy of the femoral neck severs the blood flow to the femoral head and if severance of the ligamentum teres is added the epiphysis and the adjacent metaphysis will be avascular In this series the degenerative and regenerative changes following such a procedure proved to be fairly constant The histological signs of vascular disturbances appeared *in the growth plate the metaphysis* and the epiphysis in this order In agreement with earlier observations (*Wollenberg* 1928 *Rokkanen* 1962 *Rokkanen Slätis & Laine* 1963) these histological changes appeared late and were not conclusive until 2–3 weeks after the operation

Lack of radioactive phosphorus in the autoradiographs can be regarded as a sign of impaired vascularity as was observed during the early stages of degeneration Neither does oxytetracyclin bring about any fluorescence in avascular bone (*Rokkanen et al* 1963 1965) and these labelling techniques give in *fact rise to* a very similar uptake pattern both in the avascular and the regenerating bone Thus early *detection of impending necrosis of* the bone can be made by either method

The route of regeneration of the necrotic femoral head was from the

metaphyseal area towards the epiphysis The process of regeneration seemed to depend on the soft tissue bridge to the femoral head growing like a callous cuff around the osteotomy The role played by the ligamentum teres in the regeneration of the femoral head was negligible The importance of this finding is not yet settled but similar observations were previously made on older rabbits (*Rokkanen et al* 1965) Further experiments on this subject with special reference to fracture repair in the femoral neck are in progress

It has been claimed that the joint cartilage survives on the necrotic femoral head owing to nutrition from the synovial fluid (*Ingelmark* 1950) The observation of oxytetracyclin labelling of the juxtachondral area in the avascular femoral head (Figure 2) is an argument in favor of independent nutrition of the cartilage

Radiographic collapse of the femoral head was not observed until the regenerative process has proceeded to the weight bearing area of the epiphysis *i e* 6 weeks after the osteotomy The collapse and in some animals an increased density of the femoral head thus coincides with the creeping substitution of the necrotic femoral head and must be regarded as evidence of revascularization of the head In this respect the series gives experimental support to the views expressed by *Bobechko & Harris* (1960) and *Bohr & Larsen* (1965)

## SUMMARY

In order to investigate the regeneration of the avascular femoral head 39 young rabbits were operated The left hip joint of 25 animals was opened the ligamentum teres severed and the femoral neck divided by subcapital osteotomy a similar osteotomy on 14 animals was made leaving the ligamentum teres untouched

The animals were sacrified 1–28 weeks following the operation and the specimens were examined radiographically histologically and by autoradiographic and oxytetracycline labelling techniques The results can be summarized as follows

1 Subcapital osteotomy of the femoral neck resulted in transient necrosis of the femoral head regardless of the state of the ligamentum teres
2 Histological signs of impaired vascularity were observed in the growth cartilage the metaphysis and the epiphysis in this order Histological evidence of bone necrosis was not undisputable until

2–3 weeks after the operation. The avascular areas of the bone were easily demonstrated by the autoradiographic and oxytetracycline labelling techniques.

3. Regeneration of the femoral head began about 3 weeks after the osteotomy and progressed from the metaphyseal area below towards the growth plate and epiphysis above. A fibrous sheath surrounding the site of osteotomy and adhering to the femoral head seemed to be an important factor in the regenerative process. An intact ligamentum teres did not alter the route of regeneration.

4. Collapse of the weight bearing area of the epiphysis started about 6 weeks after the osteotomy and coincided with the invasion of fibrous tissue in the necrotic femoral head.


## RÉSUMÉ

Afin d'examiner la régénération de la tête fémorale avasculaire, 39 jeunes lapins ont été opérés. L'articulation de la hanche gauche a été ouverte chez 25 animaux, le ligamentum teres blessé et le col fémoral divisé par ostéotomie subcapitale; une ostéotomie similaire a été pratiquée chez 14 animaux en laissant intact le ligamentum teres.

Les animaux ont été sacrifiés 1 à 2 semaines après l'opération et des spécimens ont été examinés radiographiquement, histologiquement et par des techniques autoradiographiques et à l'oxytétracycline.

Les résultats peuvent être résumés comme suit:

1. L'ostéotomie subcapitale du col fémoral provoque une nécrose passagère de la tête fémorale quel que soit l'état du ligamentum teres.
2. Des signes histologiques de vascularité altérée ont été observés dans le cartilage de croissance, la métaphyse et l'épiphyse dans l'ordre indiqué. Une évidence histologique de nécrose osseuse n'était pas indiscutable avant 2 à 3 semaines après l'opération. Les surfaces avasculaires de l'os étaient facilement démontrables au moyen des techniques autoradiographiques et à l'oxytétracycline.
3. La régénération de la tête fémorale commença environ 3 semaines après, progressant de la partie métaphysaire en dessous du côté de la plaque de croissance et de l'épiphyse au dessus. Une gaine fibreuse entourant l'endroit de l'ostéotomie et adhérant à la tête fémorale semble être un facteur important du processus de régénération. Un ligamentum teres intact ne modifie pas la voie de la régénération.
4. Le collapsus de la partie de l'épiphyse supportant le poids commence

6 semaines apres l osteotomie et coincide avec l invasion de ti
fibreux dans la tete femorale necrotique

## ZUSAMMENFASSUNG

Um die Regeneration des avaskularen Femurkopfes zu untersucl wurden 39 junge Kaninchen operiert Das linke Hüftgelenk von Tieren wurde geöffnet das ligamentum teres wurde durchschnitten u der Femurhals mittels subcapitaler Osteotomie durchtrennt E gleiche Osteotomie unter Belassung des lig teres wurde an 14 Tie vorgenommen

Die Tiere wurden 1–28 Wochen nach der Operation getotet und Praparate wurden röntgenologisch histologisch und mittels autorac graphischer und Oxytetracyklin Markierungstechniken untersucht I Ergebnisse konnen folgendermassen zusammegefasst werden

1 Subkapitale Osteotomie des Femurhalses hatte eine vorübergeher Nekrose des Femurkopfes gleichgultig in welchem Zustand s das ligamentum teres befand zur Folge
2 Histologische Zeichen von verminderter Gefässversorgung wur in der kartilaginaren Wachtstumszone der Metaphyse und I physe in dieser Reihenfolge beobachtet Der histologische Bew von Knochennekrose war nicht sicher vor der 2 -3 Woche nach Operation Die gefasslosen Gebiete wurden mühelos mittels a radiographischer und Oxytetracyklin Markierungstechniken monstriert
3 Die Regeneration des Femurkopfes begann ungefähr 3 Woc nach der Osteomtomie und schritt vom Metaphysengebiete unten nach aufwarts gegen die Wachstumszone und die Epiph fort Fine fibrose Scheide die den Sitz der Osteotomie umgibt u am Femurkopf haftet scheint ein wichtiger Faktor im regene tiven Prozess zu sein Ein intaktes ligam teres veränderte Regenerationsweg nicht
4 Kollaps der gewichttragenden Fläche der Epiphyse begann unge 6 Wochen nach der Osteotomie und fiel mit dem Eindringen fibrosem Gewebe in den nekrotischen Femurkopf zusammen

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# THE STUDY OF A RIB BIOPSY FROM A PATIENT WITH OSTEOGENESIS IMPERFECTA

*A Method Using in vivo Tetracycline Labeling*[1]

*By*

J R Ramser & H M Frost[2]

Received 27 xi 65

Undecalcified sections of a rib biopsy were studied in a woman with osteogenesis imperfecta who had been given a double tetracycline bone marker *in vivo* Brightfield and flourescence microscopical measurements showed that bone formation inside the cortex was three times normal speed and was fast enough to have made the rib almost three times thicker than it was had it occurred at the same rate at only one periosteal surface Both bone formation and resorption were present on the periosteal and endosteal surfaces yet the transverse dimensions of the rib were less than half of normal values A specific defect confined to the bone surface drift mechanism is shown by these findings to be present in this woman

We present here quantitative histological studies of lamellar bone tissue and cell *dynamics* in osteogenesis imperfecta done with the aid of *in vivo* tetracycline bone labeling This technique allows *rates* to be measured in histological sections because two markers are fixed in the bone separated by a known interval of time Like growth rings in trees these markers are temporally and physically stable The amount of new tissue lying between the markers compared to the total amount of tissue provides a direct measure of the rate of bone formation during the labeling interval A woman with osteogenesis imperfecta offered herself voluntarily for the study was given a tetracycline bone marker and a rib biopsy was done We had hoped to find answers to some

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[2] Orthopaedic Research Fellow Orthopaedic Research Laboratory Henry Ford Hospital supported by a public health service fellowship 1 F2 AM 24 from the National Institute of Arthritis and Metabolic Disease

[3] Associate Orthopaedic Surgeon Henry Ford Hospital Detroit Michigan



*Figure 1. An anteroposterior view of the patient's pelvis showing the narrow femoral neck, arthrokatadysis and deformity of the obturator rings and proximal femurs.*

basic and long puzzling questions about the physiology of bone in this disease such as: can the osteoblasts form lamellar bone, can the mesenchymal (i.e. progenitor) cells make new osteoblasts, or can the osteoblasts make bone fast enough?

## MATERIALS AND METHODS

*Materials*

The patient, a 51 year old woman, was diagnosed as having osteogenesis imperfecta at birth. She had 46 spontaneous fractures of various bones until 16 years of age, at which time spontaneous fractures stopped. In the three years preceding this study she has been troubled with increasing back pain, and x-rays reveal minor collapses of several vertebrae which look much like those seen in other forms of symptomatic osteoporosis. The x-rays of her pelvis and femurs are reproduced in Figures 1 and 2. She has a mild degree of hearing loss due to otosclerosis.

The patient's brother (age 55, 26 fractures, older) and sister (age 61, 17 fractures) also have the diseases, are self sufficient economically, and ceased




*Figure 2 An antero posterior view of the patient s femurs showing the bowing due to old healed fractures and shortening of the right femur due in part to anterior bowing which is concealed by the projection*

having spontaneous fractures between age 1? and 17 The sister is suffering from back pain also The parents were normal as far as the children know

The patient s serum calcium inorganic phosphate and alkaline phosphatase have repeatedly been found to be normal A hemoglobin white and differential counts urinalysis fasting blood sugar and blood urea nitrogen were normal She had blue sclerae as a child but after maturity this sign gradually disappeared as it did also in her brother and sister The patient is 46 inches tall due to deformities caused by malunions of fra tures

*Methods*

A) *Labeling* The patient was given an *in vivo* label of 900 mg.day orally of de methylchlortetracycline in divided doses for *three days* and then *ten days* later was given the drug for *six* more days (we call this the 3 10 6 label) At eleventh rib biopsy two weeks later the anteri r 5 cm was taken for study (1) The quality f the rib felt normal as it was being stripped and cut during the operation

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In our past experience this purel qualitative observation has been a reliable clue to the presence of osteomalacic bone (soft and unusually flexible) to very low turnover bone such as is f und in pers ns who have been treated for long



*Figure 1. An anteroposterior view of the patient's pelvis showing the narrow femoral neck, arthrokatadysis and deformity of the obturator rings and proximal femurs.*

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## MATERIALS AND METHODS

### *Materials*

The patient, a 51 year old woman, was diagnosed as having osteogenesis imperfecta at birth. She had 40 spontaneous fractures of various bones until 16 years of age, at which time spontaneous fractures stopped. In the three years preceding this study she has been troubled with increasing back pain, and x-rays reveal minor collapse of several vertebrae which look much like those seen in other forms of symptomatic osteoporosis. The x-rays of her pelvis and femurs are reproduced in Figures 1 and 2. She has a mild degree of hearing loss due to otosclerosis.

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*Table 1 The raw data from the patient's rib compared to age and sex comparable normals*

| | Mean OGIM | Age comarable normal |
|---|---|---|
| Cortical Cross Section Area | 5 70 mm | 14 0 mm |
| Distance between Tetracycline Rings (19 day label) | 12 μ | 17 μ |
| Number of Osteoid Seams per Section | 7.3 | 4 1 |
| Osteoid Seam Thickness Mean | 7 7 μ | 8 8 |
| Per cent Perosteal Surface Labeled (Combination of 6 labels) | 22 7 | – |
| Per cent Endosteal Surface Labeled (Our label only) | 60 7 | – |
| Number of Resorption Spaces | 5 | 5 0 |
| Circumference of Osteoid Seams | .36 mm | .3[illegible] |

*Calculations* The number of bone forming and resorbing sites are reduced to the mean per unit cortical cross section area (*symbols* $A_f$ and $A_r$ resp ) by dividing their total numbers by the cortical cross section area (8 13) The daily linear appositional rate (*symbol* $M_f$) is the mean thickness of the tetracycline banding interval divided by the corresponding number of days which was 19 (the measurements were from the outer edge of the first band to the inner edge of the second) (6 7 13) The bone formation rate (*symbol* $V_f$) was obtained by (*i*) multiplying the mean seam circumference by the mean number of seams per mm giving the total bone forming surface in the average (*i e* representative) cubic millimeter of cortical bone (13) (*ii*) then multiplying this by the mean appositional rate in millimeters per year to give the volume of new bone made in the representative cubic millimeter of rib cortex This may be expressed with an equation thus

$$V_f = A_f M_f S_f \tag{1}$$

where $V_f$ is the amount of new bone made per year in the representative cubic millimeter of bone and the other symbols have the meaning already assigned to them The solution to this equation is a volume fractional rate constant (13)

While conversion from area to volume may seem unjustified it is valid because of the optical sectioning principle underlying the analysis and because of the homogeneous longitudinal grain of rib which is studied in thin cross section (4 14) The formation rate was then converted to the *per cent* of the cortical bone that was replaced by new bone per year by moving the decimal two places to the right Because of the steady state property this figure is also within a few per cent the

This is analogous to finding how much new ice is made on skating rinks per city block in Detroit Find the mean area per rink ($S_f$) then multiply by the mean number of rinks per block ($A_f$) and multiply by the average thickness of new ice made daily per rink by flooding and freezing ($M_f$)

resorption rate and the remodeling (i.e. turnover) rate (13 15). These calculations are listed in Table 2 with age comparable normal values.

*Table 2. The calculated data for the patient are compared to sex and age comparable normals*

| | $N_f$ | $N_r$ | $M_f$ (Micron/day) | $S_f$ | $S_r$ | $V_f$ |
|---|---|---|---|---|---|---|
| OI M | 1.29 | .88 | .51 (.91) | .36 | .30 | .097 (9.7%) |
| Normal | [illegible] | .36 | .91 | .32 | .2 | .031 |
| S.D. | ± [illegible] | ± .14 | ± .3 | ± .14 | ± .15 | ± .015 |
| S.E. | .03 | .0[illegible] | .08 | < 10⁻⁴ | < 10⁻⁴ | .003 (3.1%) |

Legend: S.D. One standard deviation. S.E. Standard error of the arithmetic mean. $N_f$ Seams/mm² cortical cross section area. $N_r$ Resorption cavities/mm². $M_f$ Linear appositional rate. $S_f$ Mean circumference seams. $S_r$ Mean circumference resorption cavities. $V_f$ Bone formation rate per year. OI M Osteogenesis imperfecta.

## RESULTS

1) *In grinding the sections the bone was normally tough and was not abnormally brittle.* Microscopically there was the usual amount and a normal pattern of fuchsin permeable bone (which usually indicates low mineral density) (16).

2) There were 1.3 osteoid seams per mm² of cortical cross section area. An age comparable normal is .29/mm² (S.D. ± .2, S.E. .03) (8, 13).

3) There were .88/mm² resorption spaces. An age comparable normal is .36/mm² (S.D. ± .14, S.E. .02) (10, 13).

4) The mean seam circumference was .36 mm. An age comparable normal is .32 mm ± .14 (S.E. < 10⁻⁴).

5) The linear appositional rate (thickness of the layer of new bone added on older bone per time unit) was .57 microns/day or 203 mm/year on endosteal surfaces. The age comparable norm for both is .91 microns/day (S.D. ± .3, S.E. .06) or .33 mm/yr (S.D. ± .1, S.E. .02). Of the 22 osteoid seams present at the time of biopsy only two failed to accept the tetracycline label. The appositional rate at periosteal surfaces could not be measured because the labels were too thin and too close and their identity (i.e. our label or old labels) could not be determined.

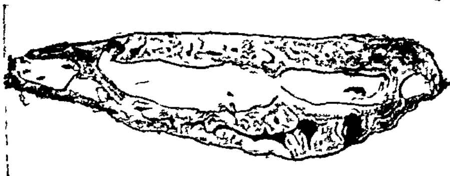


*Figure 4 The patient's rib seen in cross section taken through the distal end where some marrow cavity was present*

6) Twenty two per cent of the circumferential lamellae at the periosteum contained one or more of the six tetracycline labels this patient was known to have received (see Section 8 below and Figure 5b 5d) This reduces to 3 6 per cent per label There was no significant difference in this measurement between the cutaneous periosteal and pleural periosteal surfaces In contrast 60 7 per cent of the cortical endosteal surfaces showed the double tetracycline label we gave the patient The difference reflects the fact that endosteal surface turnover was much more rapid than periosteal surface turnover

7) Howship's lacunae were plentiful on the periosteal bone surfaces These are usually believed to designate sites of active or recently active bone resorption

8) The vertical diameter of the sections was 6 9 mm and the horizontal diameter 1 8 mm Normal values would be 12 and 3 5 mm respectively The cortical cross section area was 5 7 mm a normal value is 14 mm See Figure 4

9) There were at least five other tetracycline labels (see Figures 3 5) received before our contact with the patient when one of these antibiotics was given to treat infections The large number of bands still remaining from these other labels is proof that the number of sites of osteogenesis found at the time of biopsy was representative of her rate of bone formation

10) From a qualitative standpoint we were unable to find any abnormality in the pattern or structure of the anisotropic and isotropic lamellae in the bone when inspected between crossed polars on the polarizing microscope

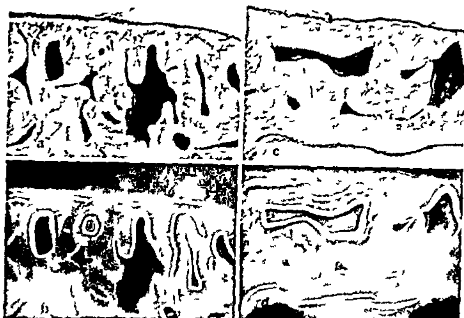



*Figure [illegible] a) About [illegible]00 × brightfield view of one of our patient's sections. b) Same field by fluorescence microscopy. The short, long and white markers lie each on the right side of the double label which we gave the patient. There are five of these in this field. The other bright bands are older labels of unknown time and duration. They show that the high turnover rate at the time of biopsy was representative of her usual turnover speed. The periosteal surface is at the top. It contains several old labels which are partly buried underneath a few microns of newer bone deposited on top of them. c) A different field from the same section, brightfield, about 300 ×. d) The same by fluorescence [illegible] Two of the double labels we gave lie in the middle of the section. The [illegible] endosteal surf[illegible] lies at the bottom and shows a series of labels [illegible] of them at this location having been the labels we gave.*

## DISCUSSION

1) A brief review is in order of some proposals that have been made about the nature of the cellular disorder in bone in osteogenesis imperfecta.

It has been said that: (i) osteoblasts cannot make adequate amounts of collagen (17), (ii) or of organic bone matrix (18, 19, 20); (iii) that progenitor cells cannot make enough new osteoblasts (19); (iv) that the collagen is defective in structure or chemistry; (v) that there is an inability to replace fibrous bone with lamellar bone (2); (vi) that the primary defect is one of impaired periosteal and endosteal bone formation (20, 22); (vii) that the defect is an impairment of periosteal and

endosteal surface *drifts* during growth (23) As Rubin recognized (22) much of the histodynamic information about the bone in this disease was obtained from infants so badly affected that they did not survive the neonatal period Their tissues may not provide reliable clues to the state and physiology of the bone of older children and in adults This is largely lamellar bone and is the subject of this study

2) In the light of these ideas the fact that the internal remodeling (*i e* cortical bone formation *plus* resorption) of this woman s rib is three times normal is very meaningful It means (*i*) she can make lamellar bone in more than normal amounts (*ii*) so her osteoblasts can make enough new bone matrix (*iii*) therefore her progenitor cells can make enough new osteoblasts and (*iv*) there is no disproportion inherent in her cells between osteoblastic and osteoblastic activity In other words her basic disorder cannot be a general inability to make and resorb bone at normal speeds at the cellular level

Caniggia Stuart and Guideri in a superb analysis (20) proposed that new bone is not added fast enough in osteogenesis imperfecta The tetracycline labeling technique (unavailable to those authors) shows that in this woman *this inability is limited to the periosteal surface* The patient did add bone at nearly normal rates (0 5 microns/day) in making Haversian systems and at quite normal rates ( 9 microns/day) in laying down cortical endosteal lamellae (6 13) If the linear rate at which she added Haversian system bone is converted to millimeters and added over the 51 years of her postnatal life bone made at this rate at only one periosteal surface would have made a rib more than 9 mm wide medio laterally (normal is only 3 5 mm) In other words the capability was there and the periosteal labels prove it so the question is why was this capability not used?

Transverse enlargement of long bones (including rib) during growth occurs by a special activity known as *drift* (24) It is caused by resorption (osteoclastic drift) or formation (osteoblastic drift) alone over a whole surface region of a bone Therefore the small transverse diameters of this woman s rib are incontrovertible evidence that her periosteal drifts were impaired

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We must stud more patients to find out if this woman is representative or if thi disease" is like osteoporosis a sign which can be caused by a group of basic all different disorders

## CONCLUSIONS

In a woman with osteogenesis imperfecta our studies showed: (i) The bone formation rate within the cortex was 3.0 times normal; (ii) the periosteal envelope of the rib was abnormally small; (iii) at the periosteal and endosteal surfaces there were a) tetracycline labeled bone forming activity and b) Howship's lacunae indicating bone resorption which c) prove that periosteal and endosteal turnover existed; (iv) the appositional rate found in her osteon formation could have made her rib three times thicker than it actually was, had this rate existed at only one periosteal surface during her 31 years of life.

These findings reveal a single specific defect in this patient's bone: defective periosteal surface drifts. It is not clear whether this defect is inherent in the bone cells or whether these cells are responding to defective "signals" from their environment.

We believe this approach to the study of this disease offers considerable hope of clarifying the basic cellular mechanisms responsible for it. It will be necessary to study more cases, and to study bones from children with the disease before we are ready to construct detailed hypotheses of what these cellular mechanisms might be.

## RÉSUMÉ

Chez une femme avec ostéogenèse imparfaite nos études ont montré: (i) le taux de formation osseuse à l'intérieur du cortex était de 3,0 fois plus élevé que de normale; (ii) l'enveloppe périostéale de la côte était anormalement étroite; (iii) il y avait dans les surfaces périostéales et endostéales a) une activité de formation osseuse décelée par la tétracycline, b) un manque de réaction Howship indiquant une résorption osseuse et qui c) prouve un renversement périostéal et endostéal; (iv) le taux d'accroissement par apposition trouvé dans la formation osseuse aurait pu rendre sa côte trois fois plus épaisse qu'elle n'était actuellement si ce taux avait existé sur une surface périostéale seulement durant les 31 années de sa vie.

Ces trouvailles révèlent une seule défectuosité spécifique dans les os de cette malade: défaut de fonctionnement de la surface périostéale. On ne sait pas si ce défaut est rattaché aux cellules osseuses ou si ces cellules répondent à des «signaux» défectueux de leur entourage.

Nous croyons que cette approche de l'étude de cette maladie accroît considérablement l'espoir d'une clarification des mécanismes cellulaires basiques qui en sont responsables. Il sera nécessaire d'étudier d'autres

cas et d examiner les os d enfants qui souffrent de la maladie avant de pouvoir batir des hypotheses detaillees sur le role de ces mecanismes cellulaires


ZUSAMMENFASSUNG

In einem weiblichen Patient mit Osteogenesis imperfecta zeigten unsere Untersuchungen

(i) Die Geschwindigkeit der Knochenbildung innerhalb der Rinde war das dreifache des Normalen (ii) die periostale Hulle der Rippe war abnormal klein (iii) die periostalen und endostalen Oberflachen hier waren a) Tetracyclin markierter Knochen in Aktivitet und b) Howships Lakunen die Knochenresorption anzeigten was c) beweist dass ein periostaler und endostaler Umsatz vorhanden war (iv) die Ansatzgeschwindigkeit ihrer Knochenbildung konnte ihre Rippe dreimal so dick gemacht haben als dies wirklich der Fall war wenn diese Geschwindigkeit nur an *einer* Oberfläche wahrend der 51 Jahre ihres Lebens vorhanden gewesen wäre

Diese Befunde enthullen einen einzelnen spezifischen Mangel im Knochen dieses Patienten Mangelvollen periostalen Oberfachenansatz Es ist nicht klar ob dieser Mangel in den Knochenzellen selbst liegt oder ob diese Zellen auf mangelhafte "Signale" von seiten ihrer Umgebung reagieren

Wir glauben dass dieser Weg zum Studium dieser Erkrankung eine bedeutende Moglichkeit darbietet um den zu Grunde liegenden Zellmechanismus aufzuklären der fur sie verantwortlich ist Es ist notwendig eine grossere Anzahl von Fallen zu untersuchen und auch kindliche Knochen mit dieser Krankheit zu studieren ehe wir so weit kommen werden dass wir eingehende Hypothesen über diese zellulären Mechanismen aufbauen konnen



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# DETERMINATION OF THE SAGITTAL MOBILITY OF THE LUMBAR SPINE

## *A Clinical Method*

*By*

OLOV LINDAHL

Received 7 ii 66

An important component of any examination of the orthopaedic patient is an assessment of the mobility in the various joints and numerical values for the ranges feature prominently in reports of the orthopaedic status As regards the lumbar spine the following mensuration methods are to be found in the orthopaedic literature

I Measurement in the erect posture of changes in angle between the thoracic spine and the vertical

II An estimate of the distance between two or more spinous processes

III Measurement of the distance from the finger tips to the floor in maximum flexion

IV Estimation of the difference in the contour of the spinal column between two extreme positions

V Registration of this difference

VI Measurment of angular changes between individual vertebrae on a lateral radiograph

I Measurement of changes in the angle between the thoracic spine and the vertical line is probably the method that has been most frequently recommended for clinical work Figure 1 shows the technique given in the Manual of Orthopaedic Surgery of the American Orthopaedic Association (11) The same recommendation is found in the special edition of J A M A for joint examination (21) as in several standard works on orthopaedic examination technique (8 12 13) The range of movement is given in J A M A as 120 (21)

II Estimation of the distance between two or more spinal processes

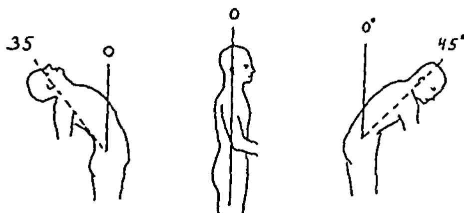



*Figure 1. Measurement of spinal mobility according to the American Orthopaedic Association.*

is often recommended (5, 8, 16, 17), but as a rule no accurate technique is given, nor have any normal values been reported.

III. Measurement of the smallest distance between the finger tips and the floor is sometimes recommended (1, 5, 11), but this can give only an impression of the magnitude of flexion. The values vary from —10 to + 30 cm, and normal values are difficult to find.

IV. Estimation of the shape of the back (lordosis, kyphosis) by eye is often recommended (1, 5, 7, 15, 19) because the mobility of the hip cannot be excluded during flexion.

V. Drawing or photographic recording of the sagittal contour or application of a pliable plastic ruler along the spinal contour in the two extreme positions is sometimes recommended (6, 22). The range of mobility can then be seen as the differences in the shapes of the curves in the two positions, and it is possible to express the angles between the different positions of the curves (22).

VI. Measurement of the mobility of two vertebrae in relation to one another can be performed most accurately on radiographs, and by combining the ranges of mobility of several disks one can obtain the total range of movement for a particular section of the column. A number of authors have described such methods (3, 4, 9, 20, 23, 24). The values for the mobility of the lumbar spine have been reported as 30–121, usually 60–80.

## COMMENTS

On the methods mentioned here it is probably only the contour method (V) and the measurement on radiographs (VI) that meet reasonable

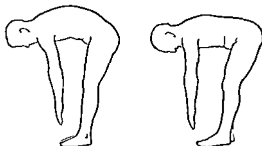


*Figure 2 Estimation of the range of mobility of the lumbar spine by examination of the varying contour (*Adams *(1))*

scientific demands on exactness The usual method of measuring the range of mobility—by the change in angle of the thoracic spine—implies an indefensibly large and didactically unacceptable source of error namely the included movement of the hip joints It is surprising that in spite of this obvious source of error the method is still commonly advocated Many authors of textbooks have however discussed this error and pointed out the need to ensure that it is the movement in the actual spine that is being measured (Figure 2) Estimation of the change in spinal contour is recommended instead (*Adams* (1))

The leg raising test or Lasegue s sign is used as a test of the degree of irritation of the sciatic nerve or its roots The test of spinal mobility in the erect posture can be said to be a standing leg raising test which may be of interest in another context For some patients the test is negative in the supine position but positive erect The reason for this is not clear but it would seem natural to suppose that in the standing position the nerve roots may be subjected to compression (via normal or herniated disks) This way of testing spinal mobility is thus informative as to spinal function but does not disclose the mobility of the lumbar spine Many authors have pointed out that the mobility of the back should be examined in the erect posture with the knees extended but *Perkins* (19) for instance prefers the seated position in which "the hamstrings and the sciatic nerve are all lax Measurement of the distance between the finger tips and the floor can be of some value when it is required to follow the status of a particular patient over a long period but this distance does not constitute a measure of spinal mobility that will serve for comparison of patients or even for judging whether the range of mobility is normal

The registration of the sagittal contour of the spine (by means of a flexible ruler shadow tracing or photographs) in maximum extension

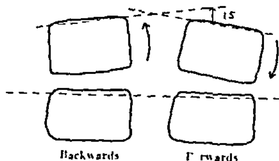



*Figure 3 Determination of the sagittal range of mobility in two adjacent lumbar vertebrae*

and flexion provides a fairly accurate record of the range of the spinal mobility One disadvantage of the method is that the recording is time consuming another that it is difficult to derive comparable numerical values from the curves It is true that one can measure the angle between L1 and the sacrum in ventroflexion and dorsal extension but this does not give the range of movement of the intervening disks (see below *Mechanics of spinal mobility* and Figure 5)

The most exact impression of the range of mobility is obtained by measurements on radiographs and the only significant source of error lies in the difficulty of obtaining the full range of mobility because of pain or discomfort and the inexactness of the terminal positions The registration itself is exact

## *Mechanics of Spinal Mobility*

To determine the range of mobility of a joint it is common to measure the change in the angle between the longitudinal axes of the two bones containing the joint The movement of a disk is certainly more complex than that in an ordinary hinge joint and sometimes involves not only a change in angle but also a translation and a displacement of the centre of motion during the movement (14) Still the chief component of the movement is an angular change and there is no difficulty in measuring such a change in angle on the radiograph (Figure 3) The numerical value obtained for the change in angle is the same whether the upper or lower surfaces or the anterior border of the vertebrae are used as reference lines

The lumbar spine as a unit consists of 5 such joints and it is the total mobility of these that is to be measured Although this total mobility

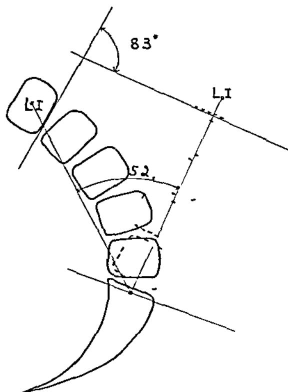



*Figure 4 Determination of the sagittal range of mobility in the whole lumbar spine (5 disks) Change in angle of the first lumbar vertebra between two extreme positions (83 ) corresponds to the sum of all the changes in angle for the individual links The angle formed between $L_1$ and the sacrum in the two extreme positions (5° ) will always be less than the preceding angle*

involves a considerable forward and backward displacement of the whole spine there is still an angular change between the upper vertebra $L_1$ in relation to the sacrum in maximum extension and flexion (Figure 4) The angular change of the uppermost vertebra in relation to the sacrum is then as great as the sum of all the angular changes in the individual joints Hence if the whole lumbar spine is considered as a single joint (albeit a long one) its range of mobility can be measured exactly in degrees A similar procedure is used in measuring the range of mobility of other joints such as the wrist which consists of 3 joints

The angle formed by the two lines joining the sacrum and the middle of the first lumbar vertebra one in full flexion and the other in full extension is likewise a kind of measure of the range of spinal mobility

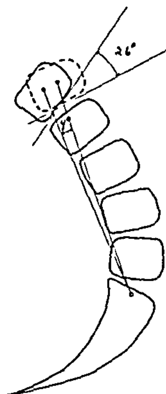



*Figure 5 When the change in the $L_1$—sacrum angle in movements is used the angle reading obtained for a given angular change diminishes the further the movement occurs from the sacrum*

This angle however does not bear any mathematical relationship to the above mentioned angle (the sum of angular changes in the 5 disks) but is dependent primarily on the length of the lumbar spine. An angular change between the upper vertebrae will give a smaller reading for the $L_1$ – sacrum angle than the corresponding change in the angle between the lower vertebrae and the sacrum (Figure 5)

### A New Clinical Method for Measuring the Sagittal Mobility of the Lumbar Spine

A new method for measuring the total sagittal range of mobility of the hip joint has been evolved by *Ahlbäck & Lindahl* (2). In earlier methods for finding the sagittal mobility of the hip the value obtained has included part of the spinal mobility. As this component can be eliminated by the new method the study was extended to include the

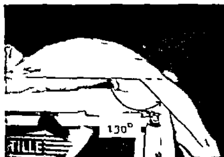



*Figure 6A. The initial position in measurement of the sagittal range of mobility of the hip and lumbar spine. In this position the angle between the thoracic spine and the thigh in full extension of both the lumbar spine and the hips is also determined.*




*Figure 6B. The range of mobility of the thigh to this position corresponds to the total sagittal mobility of the hip-joint. The pelvis and spine are kept in a fixed position by the lowered thigh.*

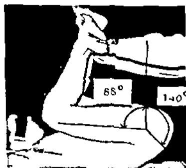



*Figure 6C. Here the combined range of mobility of the spine and hips is attained.*

combined mobility of hip and lumbar spine. By subtracting the sagittal mobility of the hip from the total, the mobility of the lumbar spine was obtained. The procedure can be applied to both hip joints, thus providing a check of the accuracy.

The examination was performed with the patient lying supine on a table over the end of which his legs hung from the hips. The thighs were lowered until lumbar spine and hips were fully extended (Figure

6 A). In this position the pelvis and lumbar spine were locked by preventing movement of one thigh. The other was flexed fully in the hip joint until a resilient resistance was felt (Figure 6 B). This part of the movement of the thigh constitutes a determination of the sagittal mobility of the hip (Ahlbäck & Lindahl (2)). The fixed thigh was then released and the flexion of the other thigh was continued up to the trunk, the lumbar spine being thereby kyphosed or flexed (Figure 6 C). For persons with an exceptional spinal mobility or a large stomach closer attention and sometimes a special technique are called for. If the extension of the lumbar spine is great the table must be quite high since the legs then may need to be almost at right angles to the thoracic spine. In flexion the abdomen may sometimes be encountered before the terminal position is reached. The thigh must then be flexed past the trunk and in the case of extreme mobility it may even be necessary to continue the movement beyond the table. When full flexion is being performed it must be ensured that the lumbar spine is not rolled up so much that the lower part of the thoracic spine is also raised from the table. When this precaution is being taken too there is a small movement between the lower thoracic vertebrae as can be seen on the radiograph and this movement will be included in the measured mobility.

In this way one can measure the change in angle of the femur first with one thigh fixed (range of mobility of the hip joint) and then with this thigh released (range of mobility of the lumbar spine). With the angle measuring device recommended by Ahlbäck & Lindahl (2) it is then possible to obtain a measure of the mobility of the hip and a measure of the combined mobility of the hip and lumbar spine. The mobility of the lumbar spine is then obtained by subtraction.

The examination can be repeated on the other side and whether the ranges of mobility of the two hip joints are the same or different two values of the residual range of lumbar spine mobility are obtained. The agreement between these values provides a check of the accuracy of the examination. From the theoretical standpoint the values shall be equal but in practice they sometimes differ by up to 10–15° because the end positions for the movements are not exact but are dependent on how strongly the joints are strained during this manipulation. If in addition the movements cause pain in one or both hip joints or the spine it will be even more difficult to obtain identical terminal positions.

Because full extension and flexion are seldom if ever performed by

ordinary people extension in particular will sometimes cause discomfort but if the movement is made slowly and carefully by gradually lowering of the legs the examination can usually be performed satisfactorily In persons suffering from back pains these difficulties are accentuated and it is sometimes impossible to complete the movement This however is a limitation that the method shares with all examinations of painful joints and where pain is being caused a determination of the range of movement will invariably involve a compromise between the tolerance of the patient and the insistance of the examiner

Apart from the range of mobility of the lumbar spine it is possible in this examination to record the angle between the thoracic spine or horizontal plane and one or both thighs in full extension of both lumbar spine and hip-joints (Figure 6 A) This value is of practical interest chiefly in the pre operative examination of a patient who is to be provided with a hip arthrodesis In determining the flexion angle that is suitable for the arthrodesis a knowledge of these angles for both thighs is of the greatest interest (*Lindahl* (18))

## DISCUSSION

In practice it is rarely necessary to determine the exact range of mobility of the lumbar spine This is suggested by the fact that the above clinical methods have been relied on for so long The more accurate radiographic methods have only been used in connection with scientific studies In the examination of a patient with back disorders and to make a diagnosis a rough estimate of any restriction of mobility will usually suffice An assessment of spinal mobility in such terms as normal slightly or considerably reduced or completely eliminated is then preferable to numerical data in degrees or centimetres

With the availability of a simple clinical method the need for more accurate data on the mobility range may well increase In particular such data can be of interest in connection with insurance For scientific use as for instance in judging the results of a certain form of treatment for a back disorder a more accurate method may also be desirable and in the determination of the position for a hip arthrodesis this technique would seem to be indispensable if the best functional position of the joint is to be found (18)

### *Range of Lumbar Spine Mobility Measured by the New Method*

In 58 patients with various diseases but no back disorders the range

of mobility of the lumbar spine was examined by the method described above. Although these subjects were not a randomized sample of a normal population they do represent an age range. The measurements showed, as expected, that the mobility diminished with age and that there were extremely large individual variations (Table 1). The examinations were performed on both legs. The differences between the two values so obtained are given in Table 2 and constitute a measure of accuracy of the determination. The angle measuring device enabled readings to be made to the nearest degree. The method itself was not so accurate as this, of course, but nothing would probably have been gained by approximating the original values.

*Table 1. Sagittal range of mobility of the lumbar spine in normal subjects distributed with respect to age*

| Age | 20–29 | 30–39 | 40–49 | 50–59 | 60–69 | >70 |
|---|---|---|---|---|---|---|
| No. of cases | 10 | 8 | 11 | 10 | 1[illegible] | 7 |
| Mean | 89 | 8[illegible] | 7[illegible] | [illegible] | 59 | 48 |
| Range | 61–10[illegible] | 55–9[illegible] | 50–93 | 51–8[illegible] | 40–7[illegible] | 31–[illegible]9 |

*Table 2. Difference between the two values for the sagittal mobility of the lumbar spine*

| Difference (°) | 0 | 1–4 | 5–9 | 10–14 | >15 |
|---|---|---|---|---|---|
| No. of subjects | 10 | 34 | 31 | 10 | 3 |

*Table 3. Thoracic spine–femur angle for normal subjects with full extension in both lumbar spine and hips distributed with respect to age*

| Age | 20–29 | 30–39 | 40–49 | 50–59 | 60–69 | >70 |
|---|---|---|---|---|---|---|
| No. of cases | 10 | 8 | 11 | 10 | 12 | 7 |
| Mean | 130 | 139 | 144 | 146 | 149 | 154 |
| Range | 111–140 | 118–148 | 1[illegible]8–153 | 1[illegible]5–16[illegible] | 134–1[illegible]8 | 131–174 |

The angles between the thoracic spine and the thighs in full extension of both hip-joints and lumbar spine are given in Table 3 (Figure 6 A). As in the case of the lumbar spine mobility this angle diminished with age.

## DISCUSSION

For the mobility of the lumbar spine J A M A (21) reports a value of 120 This is obviously too high and relates to the combined but not total mobility of the lumbar spine and hip *Fick* (10) gives 113 for a specimen *Åkerblom* (24) a mean of 73 for 3 specimens For measurements on radiographs of living subjects values of 30–83 have been reported (3 4 9 20) *Wiles* (23) obtained values of 115 and 121 for two acrobats The values given by the present method are in close agreement with those obtained by radiography on normal subjects It is possible that the values obtained here—at least at the lower ages—were slightly higher This is probably due to the inclusion of part of the mobility of the lowermost thoracic vertebrae Since this part of the thoracic spine is from a functional standpoint associated more closely with the lumbar spine than with the thorax this is not a disadvantage In their radiographic determinations *Bakke* (4) and *Schalimtzek* (20) measured forward and backward flexion from a mean or zero position which however they do not define closely Although the mean total range of mobility was much the same for the two authors *Bakke* obtained only 14 in forward flexion against *Schalimtzek's* 29 a discrepancy that may well have been due to the difficulty of defining and determining a mean position The position assumed spontaneously by the lumbar spine differs in the erect and seated positions and is affected in the erect posture by a number of factors such as bearing need for a change of position and back fatigue For this reason no such supposed mean position was determined in the present study

The range of lumbar spine mobility was examined also in some 50 cases of back disorders In these cases the mobility was of course much reduced owing to pain and the pathological conditions The ranges are given in Table 4

*Table 4 The sagittal range of mobility for cases of back disorders*

| | No of cases | Mean | Range |
|---|---|---|---|
| Ankylosing spondylitis (Bechterew's disease) | 6 | 12 | 5–21 |
| Lumbago acute | 8 | 16 | 5 27 |
| Lumbago chronic (+ degen disks) | 19 | 35 | 21–65 |
| Dorsal insufficiency | 21 | 55 | 29 82 |

SUMMARY

With the exception of measurements on radiographs the various methods reported in the literature for determining the sagittal mobility of the lumbar spine have various disadvantages and these are discussed. A new clinical method of measurement is presented which is based on one published earlier by *Ahlback & Lindahl* for measuring the sagittal mobility of the hip-joint. The mobility of the lumbar spine is obtained by subtracting the mobility of the hip from the combined mobility of the hip-joint and lumbar spine. With this method, which gives values in close agreement with those obtained from radiographic measurements, an examination was made of 58 sound backs. The mobility decreased with age. For the age range 20–29 years the mean was 89 and for the group above 70 years it was 48°.

RÉSUMÉ

A l'exception des mensurations sur les radiographies, les différentes méthodes rapportées dans la littérature pour déterminer la mobilité sagittale de la colonne lombaire ont différents désadvantages qui sont discutés. Une nouvelle méthode clinique de mensuration est présentée sur la base d'une méthode publiée antérieurement par *Ahlback & Lindahl* pour mesurer la mobilité sagittale de l'articulation de la hanche. La mobilité de la colonne lombaire est obtenue en soustrayant la mobilité de la hanche de la mobilité combinée de l'articulation de la hanche et de la colonne lombaire. Avec cette méthode qui fournit des données extrêmement conformes à celles obtenues par les mensurations radiographiques, il a été procédé à l'examen de 58 dos sains. La mobilité décroit avec l'âge. Entre 20 et 29 ans son étendue moyenne a été de 89 et pour le groupe de plus de 70 ans elle a été de 48.

ZUSAMMENFASSUNG

Mit Ausnahme von Messungen an Röntgenbildern haben die verschiedenen in der Literatur beschriebenen Methoden zur Bestimmung der sagittalen Beweglichkeit der Lendenwirbelsäule verschiedene Nachteile. Diese werden besprochen. Eine neue klinische Messungsmethode wird aufgezeigt, die zur Grundlage eine Methode der Messung der sagittalen Beweglichkeit des Hüftgelenkes hat, die früher von *Ahlback & Lindahl* veröffentlicht wurde. Die Beweglichkeit der Lendenwirbelsäule wird mittels Subtraktion der Hüftbeweglichkeit von der Gesamt

beweglichkeit des Huftgelenkes und der Lendenwirbelsaule erhalten Mit dieser Methode die Werte in enger Übereinstimmung mit denen die man bei röntgenologischer Messung findet ergiebt wurde eine Unter suchung an 58 gesunden Rucken vorgenommen Die Beweglichkeit nahm mit zunehmendem Alter ab Für den Altersbereich von 20–29 Jahren war der Umfang 89 und fur die Gruppe über 70 Jahre war er 48

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# DISCOPATHIA LUMBALIS

## *Degeneration of Lumbar Discs and their Operative Treatment*

*By*

G Chapchal G Fries J U Baumann & E Muller

Received 17 iii 66

Low back pain lumbago and ischias are common diagnoses in daily practice These conceptions do not differentiate between single aetiological groups and their pathological changes An adequate therapy however is only possible if based on an exact diagnosis Apart from neurogenic and myogenic low back pain its spinal origin can only be recognised on an x ray picture Thus changes and lesions of the vertebral bodies vertebral arches facet—joints as well as of the intervertebral discs must be considered A table of the diagnoses of 278 patients from the Orthopaedic Department at Utrecht of which one of us was chief at that time (statistics from 1 1 1959) gives information concerning the frequency of the different aetiologies

*Table 1*

| Diagnosis | Cases | % |
|---|---|---|
| Discopathia lumbalis | 108 | 39 0 |
| Spondylolysis | 77 | 27 7 |
| Spondylolisthesis | 58 | 20 8 |
| Lumbosacral anomalies | 19 | 6 8 |
| Osteoarthritis of intervertebral joints | 16 | 5 7 |

### MATERIAL

The material evaluated here consists of 147 operatively treated cases of discopathy The revision of the cases involves pronounced late control up to 12 years after the operation 125 cases from the years 1950–1958 and 22 cases from 1959 1962

## PATHOLOGY

As a mechanically functioning unit the spine can work perfectly only as long as its anatomy is normal and the static dynamic equilibrium is maintained. The same is also true for the single *segments of movement* which are made up of the unit of vertebral bodies, intervertebral discs and intervertebral joints. Only the full elasticity of the intervertebral discs, *i. e.* the integrity of their structure and their biological condition guarantees normal function within the segment of movement.

The hydrolic pressure of the nucleus which is due to its high water content guarantees its extraordinary elasticity in childhood and youth. Depending on the progressive degeneration the elasticity of the intervertebral disc decreases more and more beginning at the end of the second decade of life.

*It becomes compressed between the vertebrae which in turn come* closer together. The articular surfaces of the intervertebral joints shift and under these patho—mechanical conditions are prematurely worn out, what limits their funcion. The oedematous swollen ligaments of the arthrotic intervertebral joints cause irritation of the nerve roots with local and irradiating pain.

The tissue mass of the intervertebral disc protrudes peripherally under the pressure and pulls on the Sharpey—fibers stimulating the formation of spondylotic spikes on the vertebrae. If the main pressure of the swollen disc is directed dorsally, protrusion of its dorsal wall as a whole or a locally circumscribed prolapse into the vertebral canal ensues, causing compression symptoms.

The result is reflectory muscular immobilisation of the diseased segments with myalgia due to functional overloading and poor circulation of the respective muscle parts. When judging back pain the periosteum must be taken into account as its origin and as the medium of transmittance.

## CLINICAL PICTURE

Low back pain stands in the foreground of the *clinical picture*. In more than half the cases it is combined with irradiating pain in one leg. Only a small percentage complained about pain in both legs. It is true that there are also cases which feel irradiating pain in the lower extremities exclusively and have no backache. This concerned only about 5 per cent of the cases.

*Table 2 Localisation of complaints in 147 discopathies*

| Low back pain | Pain in one leg | Pain in both legs |
|---|---|---|
| 140 times<br>95 % | 86 times<br>58.5 % | 26 times<br>17.7 % |

Corresponding to the cramping of the musculature and fixation of a certain section of the vertebral column there is a limitation of function of the whole spine At the level of the degenerated intervertebral disc pain can be elicited by pressure and axial compression the paraspinal musculature is usually sensitive to pressure The patients are markedly hindered

*Table 3 Working capacity of 147 patients before the operation*

| Working capacity | Full | partial | Incapacitate | Information missing |
|---|---|---|---|---|
| Number of patients | 49 | 43 | 50 | 5 |
| % | 33.3 | 29.3 | 34.0 | 3.4 |

64 per cent of discopathy sufferers are partially or totally unable to work Their symptoms lasted from onset to the time of operation an average of 4 years and 10 months Most patients had repeated conservative treatment and were often forced to interrupt their work for a longer or shorter period of time So the situation becomes also a social problem

*Table 4 Sex distribution of discopathies in 147 patients*

| Sex | Number of cases | % |
|---|---|---|
| ♂ | 69 | 46.9 |
| ♀ | 78 | 53.1 |

*Table 5 Average age of 147 patients with discopathies at registration for the operation*

| Sex | Average age in years |
|---|---|
| ♂ | 39[illegible] |
| ♀ | 37 |
| ♂ + ♀ | 39 |

*Table 6. Age of 147 operated patients divided into decades*

| Decade | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| No. of cases | 1 | 23 | 60 | 47 | 14 | 2 |
| % | 0.7 | 15.5 | 40.8 | 32.0 | 9.5 | 1.4 |

We have clearly seen that there is a significant accumulation of discopathies in the 4th and 5th decade, making up 72.8 per cent of all cases. There is an average of 4½ years between the onset of symptoms and the development of a clinical syndrome which forces the patient to operation at an average age of 39 years because of the mass of complaints. The fact that women are affected not only 2½ years earlier but are also affected 6.1 per cent more frequently than men is not uninteresting. Since the male sex is generally more exposed to heavy manual work, one must look in these figures for a relationship to pregnancy and the physical exertion of the birth process. In fact the women in this series consisted mainly of mothers of several children. The accumulation of 84 per cent of discopathies in the intervertebral discs L 4–L 5–S1 confirms not only the well known fact that these discs combine the greatest functional performance but also that bodily stress plays a great role in the origin of discopathy. Therefore greater importance must be attributed to physical stress as a determining moment than to the individual constitutional disposition, since multilocular discopathies only appear in a small percentage. These statements can be corroborated statistically by the following tables.

*Table . Localisation of discopathy in 147 patients with 178 affected and operated intervertebral discs*

| Localisation | $L_1$–$L_2$ | $L_2$–$L_3$ | $L_3$–$L_4$ | $L_4$–$L_5$ | $L_5$–$S_1$ |
|---|---|---|---|---|---|
| Number of discs affected | 2 | 14 | 14 | 62 | 86 |
| % | 1.1 | 7.8 | 7.8 | 35 | 48.3 |

## THERAPY

In general practice it has frequently become customary to start treatment of lumbago or lumbago-ischias symptomatically without exact diagnostic clarification. Once the diagnosis has been made, a consequent operative therapy should be encouraged since it is only this procedure

*Table 8 Isolated and combined occurrence of discopathy*

| Discopathy | No. of cases | % | No. of discs | % |
|---|---|---|---|---|
| Isolated | 119 | 81 | 119 | 67 |
| Combined | 28 | 19 | 59 | 33 |
| | | *Combined* | | |
| Not adjacent | 1 | 3.5 | 2 | 3.6 |
| Adjacent | 26 | 96.5 | 57 | 96.4 |
| $L_{4-5}+L_5-S_1$ | 21 | 80 | 42 | 73.7 |
| Others | 5 | 20 | 15 | 26.3 |

The percentages apply to the corresponding group above.

*Table 9 Anamnestic information from 147 patients as to the cause of the discopathy*

| Anamnesis | Number of cases | % |
|---|---|---|
| Accident | 30 | 20.4 |
| Positive family history | 41 | 27.9 |
| No information | 76 | 51.7 |

The relationship to accident was only objectively confirmed in a few isolated instances.

*Table 10 Classification according to bodily stress during work (reliable data were only obtained from 88 patients with discopathy)*

| Work load | Heavy labour | Moderately hard labour | Light labour or sitting occupation | Feminine occupations with physical stress |
|---|---|---|---|---|
| Cases | 21 | 17 | 16 | 34 |
| % | 23.9 | 19.3 | 18.2 | 38.6 |

which is in a position as a causal measure to remove the pain. In principle it is the final immobilisation of the affected segment of movement. *Spondylodesis* presumes the operative inspection of the intervertebral discs by laminectomy. A herniotomy is only indicated in the specially situated cases of a dorsal protrusion of the disc. In order to bridge over the segment of movement we wedge a graft taken from the dorsal iliac crest between the spinal processes.



a   b

*a Discopathie L 4/5 preoperatively*
*b The same case postoperatively after fusion Observe the significant widening of the intervertebral space*

*The operative technique* is as follows After preparation of the affected spinal processes the *interspinal ligament is resected and the spinal processes freshened* At the same time the lumbar spine is kyphosed The distance between the prepared spinal processes is measured and a strong pelvic graft with indented ends is clamped between the spinal processes The patient is then brought into lordosis by appropriate elevation of the upper and lower ends of the operating table whereby the spinous processes come nearer to each other while the intervertebral space widens due to the graft and the disc can expand again At the same time the surfaces of the intervertebral joints are brought back into normal relationship to each other After completion of wound healing the patient receives a plaster corset in which he must lie for 3 months After this period of time the lumbar graft is so far incorporated that it can already be exposed to axial pressure In *order to avoid bending stress the recumbency plaster cast is replaced by a* shorter plaster corset which is applied in a standing position In the case of a suitable job with little physical exertion work can already be resumed at this stage The final removal of the plaster cast follows after another 3 months After a short period of care those patients with a manual job are now also able to work again

RESULTS

The results of this operative procedure in discopathies are excellent especially if the operation is carried out early Early operation should be specially strived for before changes in the intervertebral joints in the intervertebral foramina and above all in the nerve roots have developed

The quality of the results can best be judged from the working capacity of the patients The following statistics give information on the matter and a clear picture on the value of the method

*Table 11 Working capacity of 145 patients before and after operation*

| | | Working capacity | | | Not evaluated |
|---|---|---|---|---|---|
| | | Full | Partial | Incapacitate | |
| Before operation | cases | 49 | 43 | 50 | 3 |
| | % | 33.8 | 29.7 | 34.5 | 2 |
| After operation | cases | 100 | 23 | 11 | 11 |
| | % | 69.0 | 15.8 | 7.6 | 7.6 |

It is of outstanding significance that the number of patients capable of working after the operation rose to almost 70 per cent while the number of those unable to work was barely 18 per cent. Before the operation those fully able to work, those able to work part time and those incapable of working were approximately equally divided among the three groups.

It is also important that the patients can return to their old jobs, i.e. that they are not forced to change their profession due to the operation. Here also we can present very encouraging figures.

*Table 12 Change of profession after the operation of 145 patients*

| | | Number of cases | % |
|---|---|---|---|
| Profession | changed | 14 | 9.6 |
| | unchanged | 126 | 87.0 |
| Not evaluated | | 5 | 3.4 |

If one considers that 30 per cent had a hard manual job, 19 per cent a moderately hard one and that the 39 per cent of women belonged to the hard working social group, then the already low percentage of change of occupation of 9.6 per cent is insignificant.

If we consider the entire material critically, then the results are not only promising but are to be considered excellent. Unfortunately 4 patients could not be followed up. These 2.7 per cent do not influence the general evaluation of the results. If we base the evaluation on only three groups, good, satisfactory and poor, 87.9 per cent of good and satisfactory results, taking extensively into account the subjective impressions of the patients, can be designated as very satisfac-



a b

*a Discopathie L V/3 preoperatively*
*b The same case postoperatively after fusion. Observe the significant widening of the intervertebral space*

*The operative technique* is as follows. After preparation of the affected spinal processes, the interspinal ligament is resected and the spinal processes freshened. At the same time the lumbar spine is kyphosed. The distance between the prepared spinal processes is measured and a strong pelvic graft with indented ends is clamped between the spinal processes. The patient is then brought into lordosis by *appropriate elevation of the upper and lower ends of the operating table* whereby the spinous processes come nearer to each other, while the intervertebral space widens due to the graft and the disc can expand again. At the same time the surfaces of the intervertebral joints are brought back into normal relationship to each other. After completion of wound healing the patient receives a plaster corset in which he must lie for 3 months. After this period of time the lumbar graft is so far incorporated that it can already be exposed to axial pressure. In order to avoid bending stress, the recumbency plaster cast is replaced by a shorter plaster corset which is applied in a standing position. In the case of a suitable job with little physical exertion, work can already be resumed at this stage. The final removal of the plaster cast follows after another 3 months. After a short period of care those patients with a manual job are now also able to work again.

## RESULTS

The results of this operative procedure in discopathies are excellent, especially if the operation is carried out early. Early operation should be specially strived for before changes in the intervertebral joints, in the intervertebral foramina and above all in the nerve roots have developed.

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satisfied With this fact as a starting point we would like to compare objectively the 80 per cent of good results with the 17 3 per cent of moderate and poor results Thus in Table 14 we find a summary of the postoperative complaints in 25 patients without statement of the combination which can be seen from the numbers without further comment

*Table 14 Subjective complaints after the operation*

| | Number of patients | | |
|---|---|---|---|
| No complaints | | 116 | |
| Complaints | | 25 | |
| Localisation | back | one leg | both legs |
| Type of complaint | | How many times stated | |
| Pain | 21 × | 17 × | 5 × |
| Stiffness | 20 × | | |

Pain on coughing sneezing and pressing is typical We have tried to evaluate these complaints before and after the operation We obtained reliable answers from only 70 patients

*Table 15*

| Pain on coughing sneezing pressing | | |
|---|---|---|
| | Before operation | After operation |
| Number of cases | 62 | 11 |
| Percentage | 88 5 | 15 7 |

If one considers the total of all postoperative complaints in those 25 patients which must be counted among the moderately satisfied and the poor results the symptom free interval lasted 8 months after the operation Regarding the symptom of pain on coughing sneezing and pressing we would like to mention that among 147 operated discopathies we have found a herniated nucleus pulposus in only 20 cases (13 8 per cent)

Out of 147 discopathies which we operated 141 cases could be evaluated for an end result among them 116 obtained a good result and 25 were failures Expressed in percentage this is 82 2 per cent positive against 17 5 per cent negative results These numbers warrant the following conclusions

1) In the treatment of discopathies operative treatment should be undertaken as soon as possible.

2) *The operative treatment consists of a spondylodesis with exploratory laminectomy.*

3) The spondylodesis should be carried out with an iliac graft with *grooves which is clamped between the spinous processes.*

4) Postoperative immobilisation lasts 3 months in recumbency and a further 3 months in a plaster of Paris jacket.

5) Using the above *technique symptoms could be entirely relieved in* 82.2 per cent of all patients.

6) Postoperatively the ratio of number of patients with full working capacity *to those able to work partially to those unable to work at all* was 70:15:8. A change in the patients' occupation occurred in a ratio of 1:9. 9/10th of the patients returned eventually to their previous *occupation.*

7) The duration of treatment of 7 months is justified in view of the much longer period of incapacity under conservative treatment and of the final result.

## DISCUSSION

We would like to emphasize that our method of treatment and our experiences have been concerned primarily with the degenerative low *back syndrome* and *not with acute herniated intervertebral discs* which occur mainly in the third decade of life (*Kraeyenbuehl & Zander* 1953). There has been much controversy as to whether to combine *operations for intervertebral disc herniation* with spinal fusion or not, and we do not consider our contribution a general plea for intervertebral fusion in all cases of discus hernia.

In young patients with isolated acute intervertebral disc herniation without any considerable degree of accompagnying changes of the intervertebral joints careful and complete disc removal has shown favorable results in a very high percentage (*O'Connell* 1951, *Semmes & Murphey* 1954, *Bucy* 1961).

There can be no question however that discopathy leads with time to regular derangement of the intervertebral joints. For example the clinical importance of facet arthrosis was stressed by *Putti* (1932, 1933) and concomitant pathology in the ligamentum flavum of practical significance was described by *Malmros* (1942). The interrelation of discopathy with intervertebral joint arthrosis and foraminal narrowing

was also demonstrated in an anatomo-pathological study by one of us (*Baumann* 1957).

A large number of patients belonging to the group we are reporting upon suffered from a combination of symptoms originating at different points in the intervertebral segment of motion.

We agree with *Harmon* (1964) that for the therapeutic solution of the problems of low back pain and sciatica attention has too long been focused exclusively on intervertebral disc herniation. While direct nerve root compression must be eliminated, freedom from symptoms in degenerative low back disorders can best be secured by an intervertebral bone block. This opinion is corroborated by our finding that 9 out of 11 unsatisfactory results were related to failure to obtain bone fusion. The rate of failure in obtaining intervertebral fusion observed by *Harmon* (1964) following anterior interbody fusion does not differ substantially from ours. The anterior approach apparently allows the period of recumbency following the blocking operation to be reduced to about one week. We have found nerve root inspection a very important step in our procedure, which the anterior approach does not allow. As the total period of reconvalescence does not differ considerably, the posterior procedure described here is therefore preferred by the authors.


## SUMMARY

Follow up results are reported on 147 patients who had been operated for a lumbar degenerated disc syndrome by posterior exploratory partial laminectomy and interspinous fusion with iliac grafts. There were 89.7 per cent of good and satisfactory results. 87 per cent of the patients could continue their previous occupation. The advantages of a posterior approach which allows inspection of the spinal canal and the nerve roots over anterior interbody fusion are stressed.



## ZUSAMMENFASSUNG

Bericht über Ergebnisse von 147 Spondylodesen wegen Degeneration lumbaler Zwischenwirbelscheiben.
Die Nachuntersuchung wies 89.7 pro zent guter und befriedigender Ergebnisse auf. 87 pro zent der Patienten konnten ihren ursprünglichen Beruf wieder aufnehmen. Die Durchführung der hinteren Spondylodese erlaubt die Inspektion des Spinalkanals u. der Nervenwurzeln vor der Verblockung mit dem Span. Darin liegt ein Vorteil gegenüber der vorderen intercorporalen Verblockung.

1) In the treatment of discopathies operative treatment should be undertaken as soon as possible

2) The operative treatment consists of a spondylodesis with exploratory laminectomy

3) The spondylodesis should be carried out with an iliac graft with grooves which is clamped between the spinous processes

4) Postoperative immobilisation lasts 3 months in recumbency and a further 3 months *in a plaster of Paris jacket*

5) Using the above technique symptoms could be entirely relieved in 82.2 per cent of all patients

6) Postoperatively the ratio of number of patients with full working capacity *to those able to work partially to those unable to work* at all was 70 15 8 A change in the patients occupation occurred in a ratio of 1 9 9 10th of the patients returned eventually to their previous occupation

7) The duration of treatment of 7 months is justified in view of the much longer period of incapacity under conservative treatment and of the final result

## DISCUSSION

We would like to emphasize that our method of treatment and our experiences have been concerned primarily with the "degenerative low back syndrome and not with acute herniated intervertebral discs which occur mainly in the third decade of life (*Kraeyenbuehl & Zander* 1953) There has been much controversy as to whether to combine operations for intervertebral disc herniation with spinal fusion or not and we do not consider our contribution a general plea for intervertebral fusion in all cases of discus hernia

In young patients with isolated acute intervertebral disc herniation without any considerable degree of accompanying changes of the intervertebral joints careful and complete disc removal has shown favorable results in a very high percentage (*O Connell* 1951 Symmes & *Murphey* 1954 *Bucy* 1961)

*There can be no question however* that discopathy leads with time to regular derangement of the intervertebral joints For example the clinical importance of facet arthrosis was stressed by *Putti* (1932 1933) and concomitant pathology in the ligamentum flavum of practical significance was *described by Malmros* (1942) The interrelation of discopathy with intervertebral joint arthrosis and foraminal narrowing

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# OXYPHENBUTAZONE (TANDERIL®) IN SURGERY FOR HERNIATED DISCS

*A Double Blind Trial*

*By*

ALF NACHEMSON

Received 27 ix 65

Many follow up results have been reported of lumbar disc surgery performed for disc herniation but it is also stated that even if 90-95 per cent of the patients go back to work only 15-50 per cent of them claim that they are completely free from pain (2 5 7 9 16 17) Some of the poor results have been explained in terms of post operative scarring (14)

Since Oxyphenbutazone (Tanderil®) is said by many authors to reduce post operative inflammation and connective tissue adhesions and oedema (3 4 6 11 13 15 19) a double blind study on the effect of this drug in lumbar disc surgery was performed and is reported here in order to evaluate its effect on the post operative course

## MATERIAL

Fifty four consecutive cases of surgically proved herniated discs were studied All operations were performed by the author The pre-operative diagnosis was determined by the clinical examination and confirmed by a positive myelogram using a water soluble contrast (abrodil) (1 8) The same operative technique was used in all cases i e infiltration with a weak adrenaline solution down to the arches a midline incision with the patient prone on the operating table chiseling off the musculature with a broad chisel and performing a narrow hemi laminectomy followed by excision of the ligamentum flavum and extirpation of the prolapsed material No attempt was made to evacuate the entire disc Control of bleeding was routine Sponges and suction bottle were weighed and the amount of bleeding during surgery was recorded in gram The time in minutes from the opening of the skin until closure was noted

All patients were out of bed and standing the day following operation

Tanderil® or the blind tablet in the dosage of 200 mg three times a day were given

to the patients for one day pre operatively On the day of operation 200 + 200 mg given to be followed by 200 mg × 3 for 8 more days and then 100 mg × 3 for another 4 days

Postoperatively the patients were given some analgesics according to a present program A weak drug was given at first followed by progressively stronger drugs The analgesic effect was divided into five groups according to pharmacological strength ranging from aspirin to morphine and one tablet from each group was given a score of 1 5 respectively

The amount of reaction around the wound was noted and this was scored on a 0 3 scale (No reactions 0 minimal reaction 1 definite redness and swelling 2 discharge from wound and burying of the sutures 3

Emesis was watched for as a possible indication to discontinue the drug

Prior to preoperative administration of the drug a haemoglobin determination white blood cell count and thrombocyte count were performed This was repeated three days post operatively and two weeks post operatively in all cases

The clinical history of the patients was carefully noted pre and post operatively until they regained employment All cases were followed personally by the author the average number of visits after discharge from hospital was four times

The final follow up was made exactly one year following surgery in each case by personal interviews The patients were asked if they had any pain either in the leg in the back or in both if they could return to their previous work or if they had to change to less strenous work In the examination the movements of the back were noted the scar was inspected and palpated for tenderness and a thorough neurologic examination was performed The patients were asked if they thought they were perfectly well and symptom free and if they regarded themselves as nearly perfect the same as before or worse following the surgery (Table 1)

*Table 1 Follow up Scheme*

The numbers in (brackets) refer to the points given to each answer
The sum is the follow up score

A Any symptoms like tiredness strain stiffness every day (3) once a week (2) once a month (1) never (0)
B Pain in back every day (3) once a week (2) once a month (1) never (0)
C Pain in leg every day (3) once a week (2) once a month (1) never (0)
D Occupation postoperatively

| | |
|---|---|
| heavy work | (0) |
| middle (housewife) | (1) |
| light work | (3) |

E Mobility of low back same as prior to illness (0) somewhat less (1) definite restriction (2)
F Increase of neurologic loss post operatively (2)
G Lasègue s sign negative (0) 60 80 (1) <60 (2)
H Any need of analgesic (2)
I Are you perfectly well (0) nearly perfectly well (1) improved (2) the same as preoperatively (3) worse than before the operation (4)

After the completion of the investigation the code of the tabletes used was opened and it was found that of the 54 patients 27 had received Tanderil® and 27 the placebo

All 54 cases were utilized in the evaluation of the early post operative course Four were excluded from the one year follow up one in each group for each of the following recurrence of sciatica with re operation within a year and superimposed concomitant illness In both of the latter instances the patients stated that the result was good

## RESULTS

### A *The Effect of Oxyphenbutazone on the Early Post Operative Course*

This period lasted from the day of operation to the return to work During this period the following variables were noted 1 Haemoglobin white blood cell and thrombocytes counts pre and post operatively 2 Duration of the operation 3 Amount of bleeding 4 Total score of analgesic drugs given to the patients (according to a 1–5 point scale) 5 Total increase in temperature (increases above 37 0 in the morning and 37 5 in the afternoon were summed up) 6 Oedema and reaction around the scar 7 Return to work in weeks post operatively 8 Return of pre-operative neurologic loss 9 Straight leg raising test 3 months post operatively

The patients examined are separated into two groups of the same size one group of patients receiving Tanderil® and the other group receiving the placebo

No cases of post operative thrombosis urinary tract infections or other complications occurred

The $\chi$ test or Student s t test were used to ascertain if the two groups could be regarded as equal with respect to the following variables age sex pre operative symptoms in number of months and straight leg raising test (Lasegue s sign) pre operatively No significant differences were found with respect to these four variables Thus the Tanderil® and placebo groups can be regarded as completely comparable (Level of Significance 5 per cent)

The mean difference between the pre-operative and post-operative values for the variables grams of haemoglobin number of white blood cells and number of thrombocytes showed that Tanderil® did not affect any of these variables differently from the placebo (Level of Significance 5 per cent)

In Table 2 the results of Student s t test are shown for the variables nos 2–5 mentioned earlier The test was used to find out if the differ

ence between the mean value of the Tanderil® group and the mean value of the placebo group can be regarded as statistically sufficient or in other words if any significant difference exists

As shown in Table 2 Tanderil® has a sufficient statistically reducing effect on the three variables A) the amount of bleeding at operation B) total score of post operative analgesic and C) post operative added temperature rise

*Table 2*

| Variable | Tanderil® Mean | Tanderil® Varians | No | Placebo Mean | Placebo Varians | No | *Result* |
|---|---|---|---|---|---|---|---|
| Duration of oper., min | 42 | 150 | 27 | 45 | 227 | 27 | not signif |
| Bleeding gm | 164 | 19623 | 27 | 273 | 47506 | 27 | *signif* |
| Total score of analges | 17 | 116 | 27 | 24 | 205 | 27 | *signif* |
| Total incr in temp C | 1 2 | 0 7 | 27 | 1 9 | 1 9 | 27 | *signif* |
| Incapac post op weeks | 12 | 23 | 27 | 12 | 43 | 27 | not signif |

On the other two variables shown in the Table Tanderil® can be said to have no statistical effect

It can also be shown (with F test) that the variability in the results for total post operative temperature rise and bleeding are significantly less within the Tanderil® group than within the placebo group

Regarding the variables oedema and reaction around the sutures no difference was found using χ test

B *The Effect of Oxyphenbuta one in the Follow up Results*

For evaluation on the late effect 50 patients were available 25 in each group All were examined by personal interview

As in most other follow up series presented not all the patients were absolutely free from any symptoms *although all regarded themselves* as cured and were back working 26 patients were absolutely free from residual pain or stiffness 15 in the placebo group and 11 in the Tanderil® group

*Table 3*

| Variable | Tanderil® | | | Placebo | | | Result |
|---|---|---|---|---|---|---|---|
| | Mean | Varians | No | Mean | Varians | No | |
| Follow up score | 3 6 | 10 5 | 25 | 3 5 | 7 0 | 25 | not signif |

*Table 4*

| Bleeding ml | Analg score | | |
|---|---|---|---|
| | ≥ 20 p | < 20 p | |
| ≥ 250 | 3 | 3 | 6 |
| < 250 | 7 | 14 | 21 |
| | 10 | 17 | 27 |

$\chi$ obs < 1

*Table 5*

| Bleeding ml | Raise in temp | | |
|---|---|---|---|
| | ≥ 1.2 | < 1.2 | |
| ≥ 250 | 2 | 4 | 6 |
| < 250 | 9 | 12 | 21 |
| | 11 | 16 | 27 |

$\chi$ obs < 1

A standard form was used in each case (see Table 1) Each answer or positive finding was given a point as indicated The total score was added for each patient and subjected to a statistical analysis (Table 3)

There was no difference between the Tanderil® and placebo groups in the amount of residual symptoms

The $\chi$ test was also used to find out whether Tanderil® had any effect on the return of pre operative neurologic loss and on Lasegue s sign or whether any difference existed between the two groups regarding return to heavy or less heavy work No such difference was found

## DISCUSSION

From the statistical evaluation presented it is clear that Tanderil® in the dosage given in this double blind trial has no effect on late residual symptoms following surgery for herniated discs

However the patients in the Tanderil® group needed less analgesics post operatively and the temperature reaction following surgery was

less. *Mathies & Scholz* (12) stated that the effect of Tanderil® post operatively could be explained by an anti hyaluronidase effect that lessens the inflammatory exudation. *Wilhelmi* (18) showed that Tanderil® is not a real analgesic drug per se.

The reduction of bleeding during surgery in the Tanderil® group is at present impossible to explain. In the Tanderil® group there was no relationship between the amount of more profuse bleeding during surgery and the need of analgesics post operatively or the rise in temperature (Tables 4 and 5). The amount of bleeding post operatively, however, is impossible to evaluate.


## SUMMARY

A clinical double blind trial was carried out on 54 patients to investigate the effect of Oxyphenbutazone (Tanderil®) in surgery for herniated discs.

With regard to age, sex, pre operative symptoms in number of months and straight leg raising test pre operatively the two groups, 27 patients in each, were completely comparable at the 5 per cent level of significance.

The statistical examination showed that Tanderil® did not affect haemoglobin, white blood cell and thrombocytes counts post operatively differently from the placebo. The duration of operation and the working incapacity post operatively in weeks were the same in both groups, 45 minutes and 12 weeks, respectively.

On the variables bleeding during surgery, need of analgesics post operatively and total increase in temperature post operatively Tanderil® has a significantly reducing effect (at the 2.5 per cent level).

No effect of the drug was noted on reaction around the scar or on return of pre operative neurologic loss nor on the straight leg raising test.

For evaluation of the late effect 50 patients were available, 25 in each group. All were personally interviewed one year following surgery. There was no difference between the Tanderil® and placebo groups in the amount of residual symptoms.



## RÉSUMÉ

Un double essai clinique a été pratiqué chez 54 malades afin d'examiner l'effet de l'Oxyphenbutazone (Tanderil®) dans la chirurgie de l'hernie discale.

En ce qui concerne l age le sexe les symptomes pre opératoires en nombre de mois et la force du signe de Lasegue les deux groupes 27 malades dans chacun etaient entièrement comparables le rapport ne differant pas en moyenne de 5 pour cent

L analyse statistique a montre que Tanderil® n affecte pas l hemo globine le nombre des globules blancs at des thrombocytes ne differant pas apres l intervention du groupe du placebo La dures de l operation et l incapacite de travail post operatoire ont ete les memes dans les deux groupes 45 minutes et 12 semaines respectivement

Tanderil® a un effet limitatif (en moyenne de 2 5 pour cent) sur les differentes hemorragies pendant l operation la necessite d analgesiques après l intervention et l elévation totale de la temperature

Aucun effet du medicament n a ete note sur la reaction autour de la cicatrice ou sur la reapparition des troubles neurologiques pre operatoires ou encore sur la force du signe de Lasegue

Pour juger des effets a plus long terme on disposa de 50 malades 25 dans chaque groupe Tous ont ete interrogés personlement un an après l operation Il n y avait aucune difference entre le groupe Tan deril® et le groupe placebo par rapport au nombre des symptomes qui restaient

## ZUSAMMENFASSUNG

Im klinischer doppelter Blindversuch wurde an 54 Patienten aus gefuhrt um die Wirkung von Oxyphenbutazon (Tanderil®) in der Chirurgie von hernierten Disken zu untersuchen

Hinsichtlich des Alters Geschlechtes voroperativen Symptomen be zuglich der Anzahl der Monate und der Lasègue schen Probe vor der Operation waren die beiden Gruppen 27 Patienten in jeder auf der signifikanten 5 Prozent Hohe vollkommen vergleichbar

Die statistische Untersuchung zeigte dass kein Unterschied in der Wirkung des Tanderil® auf das Hemoglobin die Leukozyten und Thrombozytenzahl gegenuber den Placebo postoperativ zu finden war Die Dauer der Operation und die postoperative Arbeitsunfahigkeit in Wochen war die gleiche in beiden Gruppen 45 Minuten beziehungs weise 12 Wochen

Auf die veranderlichen Faktoren wie Blutung wahrend des chirur gischen Eingriffes postoperatives Bedurfnis fur Analgetica und Ge samterhohung der Temperatur nach der Operation hatte Tanderil® eine bezeichnenderweise herabsetzende Wirkung (auf der 2 5 Prozent Hohe)

Keine Wirkung des Mittels auf die Wundreaktion dem Rückfall von präoperativen neurologischem Ausfall oder der Lasegue'schen Probe konnte beobachtet werden

Zur Bewertung der Spätergebnisse waren 50 Patienten vorhanden 25 in jeder Gruppe Alle wurden persönlich ein Jahr nach der Operation befragt Keinerlei Unterschied zwischen der Tanderil® und der Placebogruppe hinsichtlich der Menge zurückbleibender Symptome konnte gefunden werden

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# FRACTURES OF THE CARPAL BONES

By

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Received 21 ii 66

Among the fractures of the wrist most interest attaches to those of the scaphoid bone in respect to frequency as well as prognosis

In most clinics the treatment of recent scaphoid fractures is a circular plaster cast from the distal joint of the thumb to the elbow (*Bunnell* 1956 *Böhler* 1953 *Watson Jones* 1958) but occasionally mention is made of a more active treatment in the form of osteosynthesis (*Spotoft* 1963) or extension of the plaster cast beyond the elbow (*Gregersen* 1965 *Verdan* 1960) On this background we felt that it would be of interest to submit a series of conservatively treated recent carpal fractures from the Surgical Out patient Department of the University Hospital Copenhagen from the period 1951–1960

## MATERIAL

The material comprises 137 patients with 143 fractures As all were out patients the series does not include fractures complicated by dislocation in the wrist or major injuries to soft tissues The distribution on the individual carpal bones is given in Figure 1

## SCAPHOID FRACTURES

A total of 100 patients had 102 scaphoid fractures All such fractures except those which showed signs of cyst formation avascular necrosis or pseudarthrosis at the institution of treatment were included regardless of the length of time after the injury that it was instituted The fractures were grouped according to site on the basis of the anatomical localization (Figure 2)

The age distribution of the 80 males and 20 females with scaphoid fractures is shown in Figure 3 This fracture is rare in children under

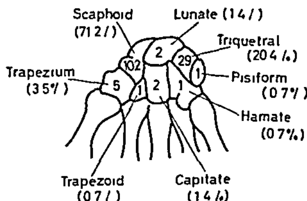



*Figure 1 Distribution of carpal fractures on the individual carpal bones*

10 years of age and in elderly persons over 70 Moreover the incidence among the males decreases steeply from the age of 40 Two patients had two fractures of the scaphoid on the same side one of them had a fracture through the middle as well as the proximal third while the other one had a fracture through the distal part and through the middle third or waist

There were no bilateral and no complicated fractures In 29 cases the injury was sustained during work in 11 cases during games 34 were due to traffic accidents (as a rule falling off a bicycle etc) while in 26 cases the genesis was mixed (falls playing etc)

In 7 cases it was impossible to confirm the diagnosis radiologically

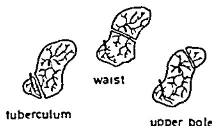



*Figure 2 Vascular supply and site of fracture in the carpal scaphoid*

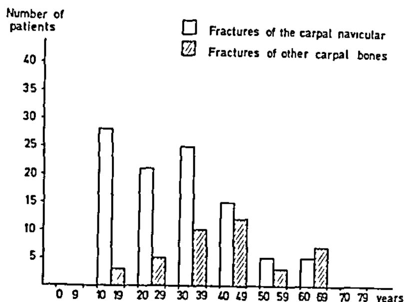



*Figure 3. Age distribution of patients with fracture of the scaphoid and of other carpal bones*

until a few weeks had passed. In 2 of these cases the fracture was not visible on the films until 3 weeks after the trauma. Only 3 of these patients were treated with a plaster cast immediately after the trauma, the others with supporting bandages.

55 fractures were right sided and 47 left sided. Four patients also had fracture of adjacent bones (Bennett's fracture, fracture of the triquetrum (2), and fracture of the lunate bone).

*Table 1. Site of scaphoid fractures*

| Site | Right | Left | Total |
|---|---|---|---|
| Distal third | 13 | 13 | 26 |
| Middle third | 34 | 32 | 66 |
| Proximal third | 8 | 2 | 10 |

Table 1 gives the distribution of the various types of fracture. It will be seen that two thirds affected the middle of the bone. In 18 cases there was slight displacement of the fragments, and in 3 of these cases a small wedge of bone had been displaced. All the patients had a history of adequate trauma. 68 were seen immediately after the trauma and

had plaster casts applied within the first 24 hours while 9 did not have plaster casts until more than 4 weeks after the trauma (Table 2)

The first plaster cast was in many cases a dorsal plaster splint which was replaced on the next day by circular plaster from high on the forearm to the knuckles including the proximal phalanx of the thumb

*Table 2 Time of application of plaster cast in relation to trauma (scaphoid fractures)*

| Site of fracture | Within 24 hours | 1–7 days after the trauma | 1–4 weeks after the trauma | more than 4 weeks after the trauma | Number of patients |
|---|---|---|---|---|---|
| Distal third | 16 | 5 | 2 | 2 | 25 |
| Middle third | 48 | 7 | 4 | 6 | 65 |
| Proximal third | 4§ | 2 | 3 | 1 | 10 |
| Total | 68 | 14 | 9 | 9 | 100 |

1 patient also had fracture of the distal third
§ 1 patient also had fracture of the middle third

*Table 3 Duration of plaster cast in weeks (patients with scaphoid fractures)*

| Site | <3 | 3–6 | 7–10 | 11–12 | 13–16 | >16 | Number of patients |
|---|---|---|---|---|---|---|---|
| Distal third | 1 | 7 | 14 | 1 | 1 | 1 | 25 |
| Middle third | 1 | 8 | 28 | 11 | 13 | 4 | 65 |
| Proximal third | 0 | 2 | 3 | 1§ | 1 | 3 | 10 |
| Total | 2 | 17 | 45 | 13 | 15 | 8 | 100 |

1 of the patients also had fracture of the middle third
§ This patient also had fracture of the distal third

It was endeavoured to maintain the plaster cast until X rays showed the fracture line to be blurred by callus As far as fractures of the distal third of the bone are concerned Table 3 shows that more than half were in plaster for 7–10 weeks while patients with fracture affecting the middle third were kept in plaster for 7–16 weeks in most cases about 10 weeks In the event of fracture affecting the proximal third of the bone the duration of the plaster treatment varied widely

Only 1 patient had radiologically confirmed avascular necrosis of the proximal fragment This patient was treated by plaster cast for 5 months after which union had occurred

## FRACTURES OF OTHER CARPAL BONES

This group comprises 40 patients One had fracture of the trapezium as well as trapezoid 3 patients also had fracture of the scaphoid

Thirty patients were males and ten females The age distribution is listed in *Figure 3*

Practically all the fractures of this group were due to falls They often presented themselves radiologically as chips especially from the dorsal aspect of the triquetrum The distribution of the fractures on the individual bones is shown in Figure 1 In one case there was a transverse fracture of the triquetrum in one case of the trapezium and in one case of the trapezium as well as trapezoid The last mentioned case represented the sequelae of a direct trauma

21 fractures were right sided and 19 left sided

The treatment was by *dorsal plaster splint* in most cases for 3 or 4 weeks but it should be mentioned that in 15 cases the plaster was left for 6 weeks or longer

## FOLLOW UP ON PATIENTS WITH SCAPHOID FRACTURES

The average follow up period is roughly 8 years Out of the 100 patients 3 have died and 5 have gone abroad Of the remaining 92 we succeeded in examining 76 clinically in their homes or in the out patient department while 71 also had radiographic examination comprising antero posterior lateral and oblique views Sixteen patients could not be examined either because they refused or because they could not be found in the national registry

*Of the 71 patients who were examined clinically as well as radio* graphically 15 were females and 56 males Only these 71 patients will be included below One patient having fracture of the proximal third as well as of the waist is listed in the tables only as a fracture of the proximal third The 5 patients for whom we lack radiographic follow up were symptom free

In 45 patients the clinical examination showed normal conditions and 42 of these patients also showed normal X ray appearances at follow up (Table 4) A total of 55 had normal X ray appearances but 13 of this group had complaints

Functionally (subjectively) ideal results *i e* no complaints were found in 46 patients In 22 cases there were occasional complaints

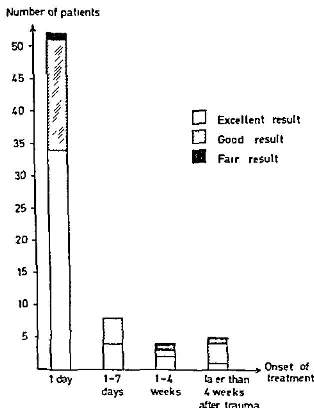



*Figure 4 Relation between functional result and the time of institution of treatment in patients with fracture of the scaphoid bone*

*Table 4 Clinical radiological and functional results at follow up in 71 patients with scaphoid fracture (The figures in brackets indicate patients who showed normal conditions clinically as well as radiologically)*

| Site | No | No clin abnorm | No radiol abnorm | No funct abnorm | Functional result good | Functional result fair | Functional result poor |
|---|---|---|---|---|---|---|---|
| Distal third | 17 | 11(10) | 14 | 11 | 5 | 1 | 0 |
| Middle third | 44 | 31(30) | 36 | 32 | 11 | 1 | 0 |
| Proximal third | 10 | 3( 2) | 5 | 3 | 6 | 1 | 0 |
| Total | 1 | 45(4 ) | 55 | 46 | 22 | 3 | 0 |

## FRACTURES OF OTHER CARPAL BONES

This group comprises 40 patients. One had fracture of the trapezium as well as trapezoid. 3 patients also had fracture of the scaphoid.

Thirty patients were males and ten females. The age distribution is listed in Figure 3.

Practically all the fractures of this group were due to falls. They often presented themselves radiologically as chips, especially from the dorsal aspect of the triquetrum. The distribution of the fractures on the individual bones is shown in Figure 1. In one case there was a transverse fracture of the triquetrum, in one case of the trapezium and in one case of the trapezium as well as trapezoid. The last mentioned case represented the sequelae of a direct trauma.

21 fractures were right sided and 19 left sided.

The treatment was by dorsal plaster splint in most cases for 3 or 4 weeks, but it should be mentioned that in 15 cases the plaster was left for 6 weeks or longer.

## FOLLOW UP ON PATIENTS WITH SCAPHOID FRACTURES

The average follow up period is roughly 8 years. Out of the 100 patients 3 have died and 5 have gone abroad. Of the remaining 92 we succeeded in examining 76 clinically, in their homes or in the out patient department, while 71 also had radiographic examination comprising antero posterior, lateral and oblique views. Sixteen patients could not be examined, either because they refused or because they could not be found in the national registry.

Of the 71 patients who were examined clinically as well as radiographically, 15 were females and 56 males. Only these 71 patients will be included below. One patient having fracture of the proximal third as well as of the waist is listed in the tables only as a fracture of the proximal third. The 5 patients for whom we lack radiographic follow up were symptom free.

In 45 patients the clinical examination showed normal conditions and 42 of these patients also showed normal X ray appearances at follow up (Table 4). A total of 55 had normal X ray appearances, but 13 of this group had complaints.

Functionally (subjectively) ideal results, i.e. no complaints, were found in 46 patients. In 22 cases there were occasional complaints

*Table 6 Functional result in relation to time of institution of treatment and duration of plaster cast in patients with scaphoid fractures*

| Site | | No of pts | Time of institution of treatment | | Duration of plaster cast | | | Interruption of the treatment |
|---|---|---|---|---|---|---|---|---|
| | | | < 1 week | later | 3–6 weeks | 7–12 weeks | > 12 weeks | |
| Distal third | I | 11 | 10 | 1 | 5 | 6 | 0 | 1 |
| | G+F | 6 | 4 | 2 | 1 | 5 | 0 | 3 |
| Middle third | I | 32 | 30 | 2 | 7 | 19 | 6 | 4 |
| | G+F | 12 | 10 | 2 | 0 | 6 | 6 | 8 |
| Proximal third | I | 3 | 3 | 0 | 1 | 1 | 1 | 1 |
| | G+F | 7 | 5 | 2 | 1 | 3 | 3 | 1 |
| Total | | 71 | 62 | 9 | 15 | 40 | 16 | 18 |

I Ideal G Good F Fair

In 3 of the 29 patients the treatment had been complicated by reflex dystrophy as compared with 1 case in the group of symptomless patients It applies to the group of patients suffering from sequelae that only 64 per cent were treated within the first 24 hours while this was done in 83 per cent of the patients without sequelae The percentage of patients seen more than 4 weeks after the trauma is also higher among patients having symptoms at follow up than among those who were symptomless On the other hand there does not appear to be any major difference between the duration of the plaster cast treatment in the two groups (Table 4)

## FOLLOW UP ON PATIENTS WITH FRACTURES OF THE OTHER CARPAL BONES

In the group of patients having fractures of the other carpal bones 2 had died during the follow up period Of the remaining 38 we examined 30 Six had complaints in the form of mild pain on exertion and these patients were X rayed Normal appearances were found in 4 while in 2 there was non union of the avulsed fragment Five of these six patients had been immobilized for more than 7 weeks and all had been treated on the day of the accident

## DISCUSSION

The most common juxta-carpal fracture is Colles' fracture. Its ratio to scaphoid fracture has been stated by *Scudder* (1938) as 10 : 1. The other carpal bones are more rarely fractured. The reported frequency differs somewhat, probably depending upon how often a distortion of the wrist is X-rayed. Among 175 carpal fractures *Kellam & Gorey* (1945) found 6 per cent to affect the triquetrum, while in our series these fractures made up 20 per cent. *Andersen & Therkelsen* (1949) found the scaphoid to be fractured 4–5 times as often as all other carpal bones together, a ratio which in our series is only 2–3 times.

After the treatment described above we found at follow-up of the patients with scaphoid fractures that about 60 per cent exhibited completely normal conditions clinically as well as radiologically. Four patients (6 per cent) had developed pseudarthrosis at the site of the fracture, while 94 per cent had united. This corresponds to the healing rate found by others (*Böhler* 1963, *Soto-Hall & Haldeman* 1941, *Stewart* 1954, *Watson-Jones* 1958) after an average treatment period of 8–10 weeks.

An analysis of the 4 cases of pseudarthrosis revealed that in 1 patient with fracture of the proximal third the treatment was instituted on the day of the accident but concluded only 6 weeks later, when the fracture had united clinically but not radiologically. One patient failed *to attend for further treatment, and one did not present* himself until 5 months after the accident, and non-union persisted in spite of plaster cast for another 5 months. In 1 patient who presented himself for treatment 4 weeks after the accident the fracture united in 9 weeks, but follow-up radiographs revealed pseudarthrosis and incipient osteoarthritis. A later injury was not known to have occurred. In 2 of the cases the plaster cast could and should have been continued for a longer period.

Like others before us we found all fractures of the distal third of the scaphoid to have united, regardless of the duration of treatment or the time of its institution. However, 6 of the patients included in the follow-up had complaints after fractures of this site, and radiographs showed that 3 had healed with slight displacement.

Better clinical results might perhaps have been obtained by a stricter treatment like e. g. *Böhler's* (1953), who considers that even a short lasting removal of the plaster, e. g. for radiography, compromises the treatment. At least the patients with a history of late institution of

treatment and interruptions in the treatment belong mostly to the group having sequelae

Figure 4 sets out graphically the functional result in relation to the time of treatment for the 71 patients with scaphoid fractures who were included in the clinical and radiological follow up The earlier the treatment is instituted the greater are the chances of an ideal result This is in complete agreement with *e g* *Andersen & Therkelsen* (1949) Half of their patients treated with plaster cast started on the treatment more than 1 weeks after the accident and correspondingly their rate of radiological union was as low as 80 per cent

In spite of the fact that 26 patients showed clinical sequelae at follow up the functional result was good in practically all cases as only 3 patients had complaints interfering with their working capacity

Where the fractures of the other carpal bones are concerned we found among the common fractures of the triquetrum predominantly minor chip fractures This accords with *e g* *Fairbank* (1942) who found these to amount 90 per cent of the fractures affecting this bone

Bandaging for a few weeks usually results in completely normal clinical conditions and radiological non union does not as in fractures of the waist or proximal third of the scaphoid bear any relation to the final therapeutic result (*Mark* 1960) *Wagner* (1959) who recommends immobilization for 4–6 weeks emphasizes the importance of early immobilization All the patients included in the present follow up showed functionally ideal or good results the few patients who had mild complaints at follow up had been bandaged immediately after the accident and the immobilization had been continued for 6–7 weeks

Thus long lasting immobilization does not appear to be required in the treatment of fractures of the carpal bones—except in dealing with fractures of the waist and proximal third of the scaphoid

## SUMMARY

A series of 137 patients with carpal fractures is presented The main stress is on a clinical and radiological follow up on 71 patients with fracture of the scaphoid The follow up period averaged 8 years The treatment was conservative a plaster cast reaching to the elbow

At follow up 94 per cent of the patients exhibited radiological union while 6 per cent (4 patients) had pseudarthrosis 60 per cent showed completely normal conditions clinically as well as radiologically 25

patients (35 per cent) had subjective complaints but only 3 so severe as to interfere with their working capacity

The authors point out the importance of instituting treatment as early as possible and of continuing it without interruption until radiological union has occurred

Among 30 patients with fracture of other carpal bones only 6 had negligible subjective complaints this applied int al to 4 with normal radiological appearances

On the basis of the present series these fractures do not appear to need long lasting immobilization


RESUME

Une serie de 137 malades avec fractures carpiennes est presentée Le plus important est un examen complementaire clinique et radiologique de 71 malades avec fractures du scaphoide La période d observation a ete en moyenne de 8 ans Le traitement avait ete conservateur un platre allant jusqu au coude

A l examen 94 pour cent des malades présentent une soudure radiologique tandis que chez 6 pour cent (4 malades) on constata une pseudarthrose 60 pour cent montrèrent des conditions entièrement normales cliniquement et radiologiquement 25 malades (35 pour cent) avaient des plaintes subjectives mais chez 3 seulement si graves qu elles influaient sur la capacite de travail

L auteur souligne l importance d instituer le traitement aussi vite que possible et de le continuer sans interruption jusqu a ce que la soudure radiologique se soit faite

Parmi 30 malades avec des fractures d autres os carpiens six avaient des plaintes subjectives négligeables a faire cela s applique en particulier a 4 chez lesquels l aspect radiologique etait normal

Sur la base de la présente serie il ne semble pas qu il soit necessaire pour ces fractures d utiliser une immobilisation qui dure trop longtemps



ZUSAMMENFASSUNG

Eine Reihe von 137 Patienten mit karpalen Bruchen wird vorgestellt Das Hauptgewicht wird auf eine klinische und rontgenologische Nachuntersuchung von 71 Patienten mit Navicularebruch gelegt Der Zeitraum der Nachuntersuchung war im Durchschnitt 8 Jahre Die Be

handlung war konservativ und bestand in einem bis zum Ellenbogen reichenden Gipsverband

Bei der Nachuntersuchung zeigten 94 pro zent der Patienten Bruchheilung während 6 pro zent ( 4 Patienten) Pseudarthrosen hatten 60 pro zent wiesen sowohl klinisch als auch rontgenologisch vollständig normale Verhältnisse auf 25 Patienten (35 pro zent) hatten subjektive Beschwerden doch nur bei dreien waren sie so schwer dass sie die Arbeitsfahigkeit beeintrachtigten

Die Verfasser heben die Wichtigkeit eines möglichst fruhzeitigen Behandlungsbeginns und der ununterbrochenen Fortsetzung der Behandlung bis zur rontgenologisch nachweisbaren Heilung hervor

Von 30 Patienten mit anderen carpalen Knochenbruchen hatten nur 6 leichte subjektive Beschwerden dies war der Fall mit al bei vieren mit normalen röntgenologischen Befunden

Auf Grund der vorliegenden Reihenuntersuchung scheinen diese Bruche keine langdauernde Ruhigstellung zu benotigen

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patients (35 per cent) had subjective complaints but only 3 so severe as to *interfere with their working capacity*

The authors point out the importance of instituting treatment as early as possible and of continuing it without interruption until radiological union has occurred

Among 30 patients with fracture of other carpal bones only 6 had negligible subjective complaints this applied in total to 4 with normal radiological appearances

On the basis of the present series these fractures do not appear to need long lasting immobilization


## RÉSUMÉ

Une série de 137 malades avec fractures carpiennes est presentée Le plus important est un examen complémentaire clinique et radiologique de 71 malades avec fractures du scaphoide La periode d observation a été en moyenne de 8 ans Le traitement avait eté conservateur un plâtre allant jusqu au coude

A l examen 94 pour cent des malades presentent une soudure radiologique tandis que chez 6 pour cent (4 malades) on constata une pseudarthrose 60 pour cent montrerent des conditions entièrement normales cliniquement et radiologiquement 25 malades (35 pour cent) avaient des plaintes subjectives mais chez 3 seulement si graves qu elles influaient sur la capacité de travail

L auteur souligne l importance d instituer le traitement aussi vite que possible et de le continuer sans interruption jusqu à ce que la soudure radiologique se soit faite

Parmi 30 malades avec des fractures d autres os carpiens six avaient des plaintes subjectives négligeables à faire cela s applique en particulier à 4 chez lesquels l aspect radiologique etait normal

Sur la base de la présente serie il ne semble pas qu il soit necessaire *pour ces fractures d utiliser une immobilisation qui dure trop longtemps*



## ZUSAMMENFASSUNG

Eine Reihe von 137 Patienten mit karpalen Bruchen wird vorgestellt Das Hauptgewicht wird auf eine klinische und rontgenologische Nachuntersuchung von 71 Patienten mit Navicularebruch gelegt Der Zeitraum der Nachuntersuchung war im Durchschnitt 8 Jahre Die Be

The majority of operations were performed by Brittain's method. In some cases the method was modified by fixing the bone graft with screws at one or both ends Table 2 shows the distribution of the material according to the indication of the operation Five patients were operated on by methods other than that of Brittain

*Table 2*

| Diagnosis | Arthrodesis No of cases | Brittain | Other methods |
|---|---|---|---|
| Poliomyelitis | 13 | 11 | 2 |
| Paresis pl brach | 1 | 1 | – |
| *Hemiplegia spastica* | *10* | *10* | – |
| Arthrogryposis multiplex | 1 | 1 | – |
| Tuberculosis carpi | 4 | 3 | 1 |
| Malacia ossis lunati | 3 | 3 | – |
| Pseudarthrosis ossis navic | 3 | 2 | 1 |
| Arthrosis carpi | 7 | 6 | 1 |
| Total | 42 | 37 | 5 |

The unit was generall immobilized in plaster for 16 weeks The plaster reached from the upper part of the brachium to the distal ends of metacarpals with the wrist in slight dorsal flexion One patient was operated according to Brockman Nissen one according to Butler and one according to Liebolt In two cases partial resection of the wrist was performed

In cases where Brittain's method was used a fracture of the graft was observed later in four patients and pseudoarthrosis in three In five of these a re-operation was performed with a good result In two patients there also occurred a fracture of the tibia from which the graft had been taken

## RESULTS OF THE FOLLOW UP EXAMINATION

It was possible to re examine 39 patients These follow up examinations were performed in 1963 and 1964 The average interval was between *the follow up examination and operation thus some 9 years (8 8)* The shortest interval was 1 year and the longest 17 years

Follow up examination showed that the operation had led to bony union in 37 cases In three of these however there were signs of a healed fracture in the distal end of the graft although the patients were unaware of a possible fracture In one patient pseudoarthrosis had occurred at the distal end of the graft but since he was treated in hospital for tuberculosis of the spine at the time treatment of the wrist was not considered indicated A reoperation was performed on

one patient with a fracture of the graft and the treatment is not yet finished

Table 3 shows the results of follow up examination judged on the basis of objective findings The result was considered objectively good if arthrodesis had led to bony union with the wrist in slight dorsal flexion or intermediate position Slight ulnar deviation was not considered to impair the result but when the ulnar deviation was more than 20 degrees the result was considered fair or poor If the operation led to bony union with the wrist in volar flexion the result was also considered fair or poor

*Table 3*

| Diagnosis | No of cases | Objective results Good | Fair | Poor |
|---|---|---|---|---|
| Poliomyelitis | 11 | 8 | 3 | – |
| Par pl brach | 1 | 1 | – | – |
| Hemipl spast | 10 | 5 | 5 | – |
| Arthrogryposis | 1 | 1 | – | – |
| Tub carpi | 4 | 3 | – | 1 |
| *Malacia lunati* | *3* | *1* | *1* | *1* |
| Pseudoarthr nav | 3 | 3 | – | – |
| Arthr carpi | 6 | 4 | 2 | – |
| Total | 39 | 26 | 11 | 2 |

*Table 4*

| *Diagnosis* | *No of cases* | *Good* | *Fair* | Poor |
|---|---|---|---|---|
| Poliomyelitis | 11 | 10 | 1 | – |
| Par pl br | 1 | 1 | – | – |
| Hemipl spast | 10 | 7 | 3 | – |
| Arthrogryposis | 1 | 1 | – | – |
| Tub carpi | 4 | 3 | – | 1 |
| Malacia lunati | 3 | 1 | 1 | 1 |
| *Pseudoarth navic* | 3 | 3 | – | – |
| Arthrosis carpi | 6 | 5 | 1 | – |
| Total | 39 | 31 | 6 | 2 |

Table 4 shows the results of follow up examination as based on the patient s subjective estimate The result was considered subjectively good if in the patient s opinion the wrist was painless under strain if it was strong and stable and if the patient was otherwise satisfied with

the result achieved If pain was felt only under strain the result was considered fair Two cases in which the operation had led to fibrous union were considered both objectively and subjectively poor

Table 5 shows the period of unfitness for work before and after operation The longest period during which a patient was unable to use his wrist was 18 years Of those patients who were not at work before operation part were still at school or engaged in later studies and thus without profession or earnings Their period of unfitness for work after operation was considered to be ended when they were able to use their hands at a trade school Three patients were prevented by other disability from starting work after operation

*Table 5*

| Period of unfitness before operation | No of cases | Period of unfitness after operation | | | |
|---|---|---|---|---|---|
| | | Below 6 m | 6–12 m | Over 1 yr | Not at work |
| Below 1 year | 15 | 12 | 3 | – | – |
| 1– 2 years | 5 | 2 | 2 | – | 1 |
| 2– 5 " | 14 | 7 | 4 | 2 | 1 |
| 5–10 | 1 | – | 1 | – | – |
| Over 10 years | 4 | 1 | 1 | – | 2 |
| Total | 39 | 22 | 11 | 2 | 4 |

*Table 6*

| Earlier type of work | No of cases | Type of work after operation | | |
|---|---|---|---|---|
| | | Heavy | Light | Not at work |
| Heavy | 12 | 10 | 1 | 1 (fr graft) |
| Light | 7 | – | 7 | – |
| Not at work | 20 | 1 | 16 | 3 (1 polio 1 epilept 1 tb spond ) |
| Total | 39 | 11 | 24 | 4 |

Table 6 shows the type of work done by the patients before and after operation Most patients returned to the same work or to a similar type of work Of the patients who had been doing heavy work only one did not return to work This was because of a fracture of the graft for




*Figure 1. Left wrist of a 25 year old female patient who had paresis of both upper and lower extremities after polio. a is one month after Brittains arthrodesis, b and c six and a half years later. The wrist is stable in 5° dorsiflexion, fingerfunction is fairly good, active pro supination 1?0°. The patient is able to perform light hand work. The result was regarded as good.*

which he was treated after the follow up examination. The treatment of this patient is not finished. Three others who did not return to work were rendered unfit by other disability. Of these, however, one polio patient is doing handwork at home so that there has been benefit from the operation.

Figures 1–3 show the results obtained by wrist arthrodesis in three cases where arthrodesis was performed on different indications.

## DISCUSSION

At the follow up examination it was surprising to note to how slight a degree a stiffened wrist hampers a patient's working ability in various trades. In manual work certain twisting movements may cause slight difficulty, but some patients were able to perform exacting manual work as automobile and lift fitters or machine fitters and repairers. Chopping movements caused pain in some cases but working ability was not prevented. When the finger function is good and forearm pronation and supination are unrestricted the patient can often compensate for a stiffened wrist by movements of the elbow and shoulder joints. Some patients were able to write freely with a stiffened wrist. One patient, however, had learnt to write with the other hand.

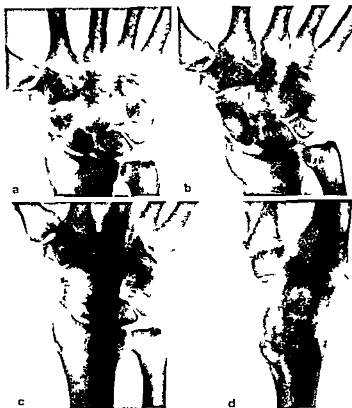



*Figure [illegible]. A 37 year old lift technician who in the winter war incurred a fracture of the carpal scaphoid. One year immobilisation in plaster gave no result. a: condition before a bone transplantation operation which led to bony union but the wrist was still painful. b: two years after the above mentioned operation. c and d: 8 years after Brittain arthrodesis. The patient obviously had a fracture of the graft at its distal end but he has not been aware of that. The wrist is now completely painless.*

For purposes of comparison Table 7 shows the primary results of the chief studies in this field published up to the end of 1963. It will be seen that arthrodesis of the wrist was performed by various methods. It is an obvious drawback of the Brittain method that the bone graft may break either in the middle or at the distal point of attachment. Brittain himself recommended the reinforcement of the graft at the centre by two smaller grafts (1952). *Haewinkel* (1962) recommended fixation of the graft by screws at the distal end but his own study showed that the graft broke in 6 cases out of 26. The distal end of the graft also projects injuriously below the skin.




*Figure 3 A 23 year old plumber who has had malacia ossis lunati for two years Immobilisation in plaster for varying periods gave no help He was not at work during these two years a before Brittain arthrodesis c and d one year and two months after arthrodesis The wrist is stable in 20 dorsiflexion active pro supination 110 finger function good The patient complains of pains after continuous pro supination movement in his work as an automobile technician*

*Table 7*

| Author | Year of publication | Method | No of cases | Good Fair | Complications |
|---|---|---|---|---|---|
| Liebolt | 1938 | Liebolt | 40 | 27 | 11 pseud<br>2 amput |
| Abbot et al | 1942 | Abbot | 48 | 47 | 1 pseudoarthr |
| Ross | 1950 | Brittain | 21 | 15 | 5 fr graft<br>1 fr III mc |
| | | Abbot | 16 | 15 | 1 pseudoarthr |
| Brittain | 1952 | Brittain | 25 | 22 | 2 fr graft<br>1 pseudoarthr |
| Evans | 1955 | Brockman | 19 | 17 | 2 pseudoarthr |
| Merle d Aubigné | 1956 | Smith Petersen | 51 | 44 | 5 pseudoarthr<br>2 fr graft |
| Mackenzie | 1960 | Seddon | 34 | 33 | 1 pseudoarthr<br>3 p oper swell |
| Hazewinkel | 1962 | Brittain | 26 | 19 | 6 fr graft<br>1 pseudoarthr |
| Danielsson–Unander Scharin | 1963 | Brittain (3 Abbot) | 16 | 12 | 3 fr graft<br>1 pseudoarthr |

Results shown in the above material as in earlier studies may be summarized as indicating that arthrodesis of the wrist joint is a suitable treatment when prolonged pain in the wrist deformity or spastic or flaccid paralysis hinders the effective use of the hand The operative methods used led in most cases to consolidation and most patients were satisfied with the result achieved In some cases in which the result was considered objectively fair because of a slight volar flexion remaining in the wrist the patient himself considered the result good


## SUMMARY

The present writer carried out a follow up examination of 42 patients on which operations aiming at arthrodesis of the wrist had been performed Thirty nine of them appeared for examination themselves The operation had led to consolidation in 37 cases There was a fractured graft in one case and a pseudarthrosis in one Judged on the basis of objective findings the results were good in 26 cases fair in 11 and poor in 2 Judged on the basis of the subjective feelings of the patients the results were considered good in 31 cases fair in 6 and poor in 2 Arthrodesis is considered desirable when pain in the wrist or a paralytic condition makes working difficult and when the use of the hand cannot be improved by other methods In most occupations bony anchylosis of the radiocarpal joint causes little or no difficulty



## RESUME

L auteur a effectue un examen complementaire de 42 malades chez lesquels avait eté pratiquee une opération tendant à établir l arthrodèse du poignet 39 se présentèrent d eux memes a l examen L operation avait abouti a la consolidation dans 37 cas Il y avait une greffe fracturce dans un cas et une pseudarthrose dans un autre Sur la base des trouvailles objectives les resultats ont été juges bons dans 26 cas assez bons dans 11 et pietres dans 2 cas Sur la base des sensations subjectives des malades les resultats ont pu etre considcres comme bons dans 31 cas relativement bons dans 6 et pietres dans 2 L arthrodese est considérée comme souhaitable lorsqu une douleur dans le poignet ou un état de paralysie rendent le travail difficile et quand l usage de la main ne s améliore pas par d autres méthodes Dans la plupart des occupations une ankylose osseuse de l articulation radio-carpienne ne cause pas ou peu de difficultés

## ZUSAMMENFASSUNG

Der Verfasser nahm eine Nachuntersuchung von 42 Patienten vor, an denen eine Operation zum Zweck einer Arthrodese des Handgelenkes ausgeführt worden war. Neununddreissig der Patienten erschienen selbst zur Untersuchung. Die Operation hatte in 37 Fällen zur Konsolidierung geführt. In einem Fall kam es zum Bruch des Transplantates und in einem anderen zur Pseudarthrose. Auf Grundlage objectiver Befunde beurteilte man das Ergebnis in 26 Fällen als gut, als mittelmässig in 11 und als schlecht in 2 Fällen. Auf Grundlage der subjectiven Meinung der Patienten waren die Ergebnisse in 31 Fällen gut, in 6 Fällen mittelmässig und in 2 Fällen schlecht. Man ist der Auffassung, dass die Arthrodese wünschenswert ist, wenn Schmerzen im Handgelenk oder ein Lähmungszustand die Arbeit schwierig macht und wenn der Gebrauch der Hand nicht mittels anderer Methoden verbessert werden kann. Für die meisten Beschäftigungen bedeutet die Ankylose des Handgelenkes nur geringe oder keinerlei Schwierigkeit.

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# ASEPTIC NECROSIS OF THE HEAD OF THE FIFTH METACARPAL

By

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Received 5. i. 66

Aseptic necrosis of the head of the metacarpals is rare. The condition was first described in 1932 by *Dieterich*. Single cases have since been reported by *Friedl* (1934), *Grossekettler* (1935), *Schinz et al.* (1952), *Seyss* (1961) and *Franke* (1962). *Dieterich* described the changes as solitary and localised to the third metacarpal. Similar changes have been demonstrated in the fourth (*Friedl*) and second metacarpal (*Grossekettler*). Multiple affection was first reported by *Bopp* (1938). As far as we know, no cases of solitary necrosis of the first or fifth metacarpal are on record.

Aseptic necrosis of the metacarpal head occurs in both sexes. Judging from the literature, the age at diagnosis ranges from 15 to 51 years. In some cases the condition produces symptoms of pain, swelling and impaired range of mobility of the joint, while in others it is asymptomatic and is discovered incidentally at roentgen examination.

The aetiology of the condition is obscure, but trauma and infection have been suggested (*Dieterich*).

The roentgenogram shows deformation of the head with irregularities of the articular surface, structural and joint space changes. The roentgenological changes are partly reversible. The necrosis appears to favour the development of arthrosis. The microscopical appearance is the same as that of other aseptic bone necrosis (*Dieterich*).

Symptomatic treatment with prolonged immobilisation has been suggested, but it is not known whether such treatment has any effect on the further course. The end result of the condition varies from complete freedom from symptoms to symptoms of the type occurring in arthrosis.

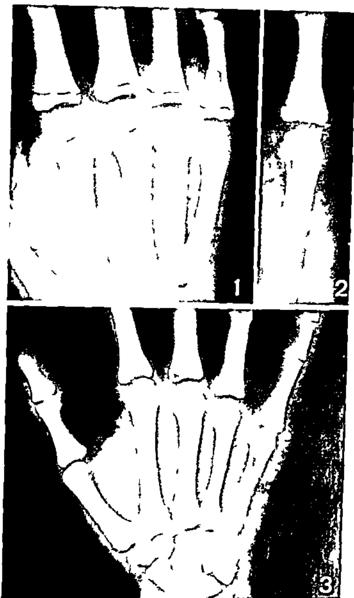



*Figure 1* *Four days after trauma In the radio volar surface of the head of the fifth metacarpal is a one mm step from which extends a thin irregular radiolucent line*

*Figure 2* *Six months after trauma Extensive destruction of the bony substance of the fifth metacarpal head with loss of bony substance structural changes throughout the head deformation of the head and destruction of the joint cartilage (narrowed joint space)*

*Figure 3* *Ten months after trauma Bone structure and joint surface of the fifth metacarpal head are now more even There is still a deformation of the head and the joint space is narrowed Notice that the epifyses of the little finger in contrast to the [illegible] of the other fingers are closed*

We have had the opportunity of seeing a case of aseptic necrosis of the head of the fifth metacarpal.

## CASE HISTORY

The patient was a [illegible] year old boy who was first seen at the department of hand surgery after a fight. He complained of pain from the metacarpo-phalangeal joint of the little finger of the right hand. Examination revealed swelling, tenderness and decreased mobility and roentgen examination a fracture was seen in the radio-volar part of the head of the fifth metacarpal (Figure 1). The [illegible] finger was immobilised in a splint for 2 weeks after which the patient was almost symptom free, and the splint was removed.

Six months later the patient returned. In the meantime he had never been completely symptom-free; trivial blows against the finger as well as heavy work causing pain. Examination now revealed a [illegible] and tenderness over the metacarpo-phalangeal joint, slightly decreased mobility ([illegible]) and crepitations on lateral movement of the joint. Roentgenography showed deformation of the metacarpal head, destruction of the articular surface, narrowed joint space and cystic rarefactions (Figure 2). E.S.R. 5 mm 1 hour. No special treatment was given.

At follow-up 4 months later considerable improvement was noted. Trivial blows against the little finger were sometimes painful but otherwise the patient had no symptoms referable to the joint, not even after heavy work. The range of mobility was still somewhat decreased (180–105°) and lateral movement still caused crepitations. Radiography showed more even bone structure and joint surface but there was still a deformation of the head and the joint space was narrowed (Figure 3). Roentgen examination of the hips, shoulders and of the left hand showed nothing remarkable.

As far as we know solitary aseptic necrosis of the head of the fifth metacarpal has not been described before. In this case the condition was probably caused by trauma.

## SUMMARY

A case of solitary aseptic necrosis of the head of the fifth metacarpal probably caused by trauma is described.

## RÉSUMÉ

Il est décrit un cas de nécrose aseptique solitaire de la tête du 5ème métacarpien probablement causée par un trauma.

## ZUSAMMENFASSUNG

Ein Fall von vereinzelter aseptischer Nekrose des capitulum metacarpi V wahrscheinlich durch Trauma entstanden wird beschrieben.

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# PROXIMAL INTERPHALANGEAL JOINT ARTHRODESIS IN RHEUMATOID ARTHRITIS

### *A Follow Up Study of 122 Operations*

*By*

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Received 21 i 66

In recent years there has been a steady increase in the surgical treatment and reconstruction of deformities of the hand caused by rheumatoid arthritis Numerous articles have appeared dealing with the general rehabilitation of the rheumatoid hand (*Flatt* 1963 *Fowler* 1963 *Inglis* 1965 *Laine Sairanen & Vainio* 1957 *Lipscomb* 1965 *Straub* 1959) Few however have gone into details or have provided adequate operative procedures It is the purpose of this paper to provide a follow up study on the treatment of various disabling deformities of the proximal interphalangeal (PIP) joints of the fingers exclusive of the thumb by a specific method namely arthrodesis utilizing Kirschner wires alone for fixation It is further felt that it is necessary to dissect the "rheumatoid hand into its component disabled parts to better evaluate the efficiency of surgical treatment At the same time one would not of course lose sight of the fact that the entire spectrum of the disease must be borne in mind and that the status of all joints in the upper extremity must be evaluated The overall goals of treatment were to provide these patients with a better functioning extremity More specifically we hoped to give a painless and stable union in a functional position in a reasonable period of time A number of goals for PIP arthrodesis was determined by *Moberg & Henrikson* (1960)

## CLINICAL MATERIAL

This series represents all the PIP arthrodeses performed at the Rheumatism Foundation Hospital in Heinola Finland from 19[illegible] 1964 There were [illegible] patients representing 1[illegible] procedures The follow up statistics on the procedures themselves

are based on the number of arthrodeses not the number of patients There were 11 males and 54 females The ages of the time of operation ranged from 17 to 61 with the average being 41 Fifteen were classified as having had the juvenile form of the disease i e an onset before age 16 The duration of the disease ranged from 3 to 35 years with an average of 15 (Table 1) Finger involvement occurred first in the course of the disease in 53 patients (81 per cent) The index finger was operated upon 19 times the middle finger 29 times the ring finger 43 times and the small finger 31 times (Table 2)

*Table 1 Clinical material*

| | |
|---|---|
| Total number of patients | 84 |
| Number of follow up patients | 65 (77 %) |
| *Total number of operations* | *150* |
| Number of follow up cases | 122 (80 %) |
| Range of ages (aver ) | 17– 61 (41) years |
| Males | 11 |
| Females | 54 |
| *Juvenile form* | *15* |
| Duration of disease (aver ) | 3– 35 (15) years |
| Length of follow up (aver ) | ½– 11 (4 ?) years |

## DEFORMITY

The rheumatoid process may cause varying deformities in the PIP joint In our series 62 fingers had buttonhole deformity 41 had intrinsic plus (swan neck) deformity, 17 had flail fingers and 2 had other causes *The large number of buttonhole deformities corresponds* with the previously reported high incidence of this deformity in rheumatoid arthritis (*Laine et al* 1957) It will be noted that the fourth and fifth fingers are particularly prone to develop this deformity The reason for this is as yet unexplained (Table 2)

*Table 2*

*Deformity related to finger involved incidence*

| Finger | Deformity | | | | |
|---|---|---|---|---|---|
| | Button hole | Swan neck | Flail | Other | Total |
| Index | 4 | 8 | 6 | 1 | 19 |
| Middle | 11 | 13 | 4 | 1 | 29 |
| Ring | 25 | 12 | 6 | 0 | 43 |
| Small | 22 | 8 | 1 | 0 | 31 |
| Total | 62 | 41 | 17 | 2 | 122 |

## FOLLOW UP

Arthrodesis of the PIP joint was performed on 84 patients of which 65 were available for follow up (77 per cent) This represented 122 operations followed and reported here out of 150 performed (80 per cent) All 65 were seen clinically and all had post operative X rays The follow up time averaged 4 2 years The longest was 11 years and the shortest 6 months An adequate length of follow up is especially important in rheumatoid disease because of the progressive nature of the disease (Table 1)

## INDICATIONS

The overall purpose of arthrodesis in these patients was to restore function When grip and digital function are impaired by virtue of joint destruction or irreparable damage to joint stabilizing ligaments arthrodesis in a functional position is indicated (*Boyes* 1964) It has been stated that fusions generally within the hand are not acceptable due to the progressive nature of the disease and that fusion previously performed to increase function may later become a liability (*Flatt* 1963) This has not been our experience in this series with the length of follow up that we have When a hand is rendered useless by the destruction of the PIP joint reconstructive procedures are indicated where possible The procedures for dealing with the PIP joint are limited Repair of the buttonhole deformity is extremely difficult in any hand and virtually impossible in the rheumatoid hand (*Flatt* 1963) The early swan neck deformity can be improved by the Littler procedure but in late cases with cartilage destruction or ligamentous instability or dislocation it is of no value (*Inglis* 1965) Capsulotomy is indicated when the integrity of the joint surface has been maintained the surrounding structures are yielding and the collateral ligaments are the chief offenders These criteria were not present in any of our cases Digital arthroplasty is of questionable value generally and in the 5 cases reported by *Cregan* (1959) all had poor results Prosthetic replacement has been adopted relatively recently and our experience with it has been limited and not very favorable The indications for its use are limited as well

Thus when patients were presented with hand function seriously impaired by severe deformity dislocation marked ligamentous instability and/or pain associated with joint destruction it was felt that arthrodesis in a functional position was indicated

## TECHNIQUE

Under tourniquet control a longitudinal midline incision is made *centered over the PIP joint* The central tendon is split in line with the skin incision The attachment of the central slip at the base of the middle phalanx is removed and the collateral ligaments are divided with care being taken not to sever the lateral bands The synovium is *excised and the cartilaginous surfaces are removed* with a small osteotome or rongeur in such a way as to achieve the desired degree of flexion when the surfaces are opposed Two crossed Kirschner wires are placed across in such a way as to engage a cortex on both the proximal and *distal phalanges Care must be taken to avoid distraction In the cases* done between 1954 and 1957 only one obliquely placed wire was used This technique has been successful in fractures (*vom Saal* 1953) This was felt to be inadequate in rheumatoid patients and since 1958 two *wires have been used as normal routine There are in addition some* special problems encountered in the rheumatoid hand which are important to note Care must be taken not to resect too much of the head of the proximal phalanx In rheumatoid arthritis it is often partly *eroded Too great a surgical resection* will reach the neck of the phalanx and bony contact with the base of the middle phalanx will be inadequate In those cases where the head is largely destroyed in its entirety by the invading synovium it may be necessary and desirable *to place the re shaped phalanx as an arrow into a target* in an effort to achieve better bony contact

If there is marked bone loss as in mutilans deformity or severe swan neck deformity a graft is placed between the prepared phalanges and wires are then similarly placed incorporating the graft This has been performed in only 4 cases The tendon is sutured together and the skin is closed with wire A pressure dressing is applied Plaster has not been used exept in a few cases with marked instability at the time of closure Five days post operatively the pressure dressing is removed and motion of the metacarpo phalangeal joints is permitted but no gripping is allowed Six weeks post operatively the finger is evaluated If it appears clinically stable nothing further is needed and the patient is permitted free use of the hand

## TECHNIQUE OF DOUBLE ARTHRODESIS

In some cases of extreme buttonhole deformity with complete luxation of both the middle and distal phalanges the following method has been

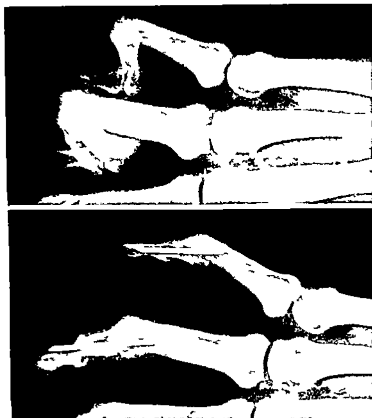


*Figure 1. In this case of extreme buttonhole deformity the middle phalanx was used like an intercalated graft. The other fixation pin has been removed.*

used. A midlateral incision is used as it may be difficult to close a dorsal incision. The middle phalanx is temporarily removed and used as an intercalated graft after appropriate shortening and remodelling. All three phalanges are fixed with two Kirschner wires in position to permit pinch with the thumb (Figure 1).

## RESULTS AND DISCUSSION

One hundred twenty two arthrodeses of the PIP joint in rheumatoid patients were followed and evaluated. The exact time of union is difficult to assess accurately but those cases appearing to have stability at six weeks after operation were permitted free use of the hand. All but eight achieved clinical and radiographic union. Of these 8 cases of non

union 6 had swan neck deformities, 3 of which were totally flail. Only 2 of the 8 had buttonhole deformities.

*Possible causes of non union were as follows. Five involved technical* difficulties with wire placement. One had only one wire placed initially. In 3 others of these 5 the wires migrated and had to be removed early and in one case the wires were placed parallel rather than in the crossed position. Two cases were in patients with amyloidosis and severe osteoporosis. *The cause of non union in one case was not known. Three of the* eight obtained fusion at a second procedure.

Of the 15 patients with juvenile arthritis all achieved union. This represented 35 operations. The procedures were carried out when the patients were adults.

*Of the 104 cases recording opposition of the thumb* 74 could not oppose pre-operatively. Eighteen could not oppose post operatively. Thus 75 per cent achieve pinch with the arthrodesed finger though they could not do this pre operatively. The chief causes of inability to pinch were deformity of the thumb as discussed in the literature (*Clayton 1962*) and fusion of the finger in a position of too much extension.

In assessing the adequacy of the position of function it was felt that 24 cases were fused in too much extension. *Straub* (1959) has stated that the position of fusion should be that position most readily adopted by these joints when the hand is at the position of rest. The optimum position of function can only be determined by taking into consideration not only the patient's general needs but the condition of the adjacent joints of the finger in question and the status of the thumb. Twenty of these 24 cases were fingers with swan neck deformity. Four were flail fingers. Only four required osteotomy to allow adequate use of the hand. The others were either functionally useful as such or the difficulty could better be helped by surgery on the deformed thumb. In addition some of these patients who were unable to oppose were able to grip and were satisfied. Grip itself was not statistically evaluated.

*Table 3 Complications in 12[illegible] cases*

| | |
|---|---|
| Non union | 8 |
| Too extended | 24 |
| Second operation needed for position | 4 |
| Too flexed | 1 |
| Ulnar deviation at *PIP* (10–15 ) | 6 |
| Absence of pinch post oper (total) | 18 (of 104) |
| Absence of pinch due to thumb deform | 10 |
| Infection | 3 |

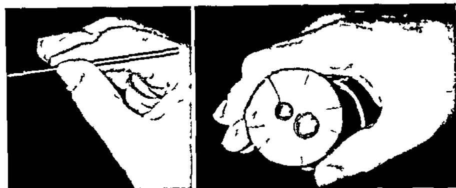


*Figure 2 The same hand in Figure 1 Before the operation the patient was not able to touch the fingertips with the thumb Good grip was obtained after fusion of all the interphalangeal joints and the metacarpophalangeal joint of the thumb*

but it was our impression that those patients with successful arthrodesis obtained improved grip unless other changes in the hand prevented it There were no rotational malalignments but 6 fingers were fused in 10–15 degrees of ulnar deviation at the PIP joint (Table 3)

The involvement of other joints of the finger in question was not thought to be a contra indication to PIP arthrodesis Four cases had fusions of the distal interphalangeal joint as well as the PIP joint of the same digit with good function resulting (Figure 2)

Fourteen cases had fusions of PIP joint with arthroplasty of the metacarpophalangeal joint of the same digit though not at the same time Their function too was good in allowing improved use of the hand (Figure 3) The position of fusion in these hands must be carefully considered

By avoiding plaster immobilization the other joints of the hand are permitted free motion This is an advantage in any hand and especially in the rheumatoid patient where extensive immobilization may seriously reduce the range of motion in involved joints

Infection occurred in 3 cases All healed without further difficulty by secondary intention

The possibility of gaining fusion in a high percentage of cases without the need of an intra medullary bone graft as used by *Moberg & Henrikson* (1960) is also advantageous in making the procedure less complex especially in view of the structure of the bone involved In selected cases however the use of cancellous graft from the crest of the ilium may be necessary to achieve better functional position espe

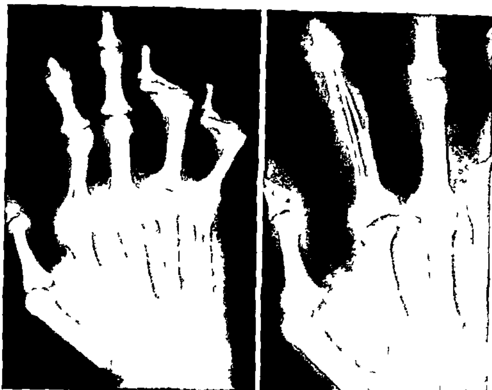


*Figure 3 A Destruction of the metacarpophalangeal and proximal interphalangeal joints of the II–III fingers B Five years after fusion of the proximal interphalangeal joint of the index and resection arthroplasty of the II III metacarpophalangeal joints the patient is working as a professional typewriter*

cially in cases with hyperextension deformity accompanied by marked bone loss

## SUMMARY AND CONCLUSIONS

1 A follow up study of 122 cases of arthrodesis of the proximal interphalangeal in rheumatoid arthritis is presented

2 Union was achieved primarily in 93 5 per cent of cases with the use of Kirschner wire fixation alone as noted in the text

3 Union pinch and adequate position for function were more difficult to obtain in fingers with swan neck or flail deformity than in th button hole type of deformity Possible reasons for this are outlined

4 Seventy five per cent of patients who could not oppose to the thumb pre operatively could do so after fusion

5 Grip was generally improved with successful fusion

6 In cases with severe osteoporosis or bone loss the use of a cancellous bone graft improves the possibility of obtaining solid fusion in the desired position

7 Involvement of other joints of the same finger is not of itself a contra indication to arthrodesis The position of fusion in these cases must be carefully considered

8 The possibility of gaining fusion in a high percentage without plaster immobilization is of particular benefit to the rheumatoid patient

## RESUME

1 Il a ete presente une enquete portant sur 122 cas d arthrodese de la phalange proximale dans des cas d arthrite rheumatoide

2 La soudure s est etablie primairement dans 93 5 pour cent des cas a l aide de la seule fixation par fil Kirschner comme note dans le texte

3 La soudure la faculte de pincer et la position adequate de fonction ont ete plus difficiles a obtenir pour les doigts avant une deformite en cou de cygne ou de fleau que dans ceux du type de la deformite en boutonniere On a cherche a en donner les raisons possibles

4 75 pour cent des malades qui ne pouvaient pas opposer le doig au pouce avant l operation pouvaient le faire apres

5 La faculte de saisir etait généralement amelioree apres une bonne fusion

6 Dans les cas atteints d osteoporose grave ou de perte osseuse l usage d une greffe osseuse poreuse ameliore la possibilite d obtenir une bonne fusion dans la position souhaitet

7 Le fait que d autres articulations du meme doigt sont impliquees n est pas en soi une contre-indication de l arthrodese Dans ces cas toutefois la position de la fusion doit etre minutieusement prise en considération

8 La possibilite d obtenir la fusion dans un pourcentage eleve des cas sans immobilisation dans le platre est particulièrement a l avantage des malades rheumatisants

## ZUSAMMENFASSUNG

1 Eine Nachuntersuchung von 122 Fällen von Arthrodese des proximalen Interphalangealgelenkes bei chronischem Gelenksrheumatismus wird vorgelegt

2 Primare Vereinigung wurde in 93 5 Prozent der Falle mittels alleiniger Kirschnerdrahtfixierung wie im Text beschrieben erzielt

3 Vereinigung, Griff und angemessene Funktionsstellung waren schwieriger bei Fingern mit Schwanenhals oder Wackeldeformität als bei der Knopflochdeformität zu erreichen. Die möglichen Gründe dafür werden skizziert.

4 Fünfundsiebzig Prozent der Patienten, die vor der Operation nicht gegen den Daumen opponieren konnten, vermochten es nach der Versteifung.

5 Das Greifen war im allgemeinen nach erfolgreicher Versteifung verbessert.

6 In Fällen mit schwerer Osteoporose oder Knochenverlust verbessert die Verwendung eines Spongiosaspahnes die Möglichkeiten eine solide Versteifung in der gewünschten Stellung zu erhalten.

7 Das Ergriffensein von anderen Gelenken am selben Finger ist an und für sich keine Kontraindikation für eine Arthrodese. Die Stellung der Versteifung muss in diesen Fällen besonders sorgfältig erwägt werden.

8 Die Möglichkeit, in einem hohen Prozentsatz eine Versteifung ohne Gipsruhigstellung zu erhalten, ist besonders wertvoll für den rheumatischen Patient.

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# SOME NEW ASPECTS OF THE TREATMENT OF CONG DISLOCATION OF THE HIP (CDH) ACCORDING TO PALMÉN–VON ROSEN

By

HANS EMNÉUS

Received 14 i 66

Early diagnosis (*Ortolani* 1948) and prompt treatment (*von Rosen* 1956 and *Palmen* 1961) are now the rule in congenital dislocation of the hip (CDH) in newborns in Sweden

According to *Andren & Borglin* (1961) in CDH the excretion of oestrone and of oestradiol in the urine is increased during the first 6 days of life *Andren* (1962) demonstrated the presence of instability of the pubic symphysis in newborns with CDH It appears that the hip joints are not stable either This instability is no longer demonstrable after the sixth day of life This prompted us to modify our principles of examination and treatment of newborns for CDH While we formerly examined all suspect CDH roentgenographically since 1961 we have relied on the clinical diagnosis This modification was decided upon in collaboration with our chief radiologist (Dr O Norman) We always use the abduction frame at the slightest suspicion of CDH but we have shortened the period of treatment to 6 weeks

These modifications are based on the following grounds

Some patients are referred to us from hospitals in small towns in the south of Sweden (Trelleborg Ystad Hörby and Landskrona) Many of these children are 5–6 days old or even older when first seen by us at the department of Orthopaedics Lasarettet Lund Only one of these small hospitals has a department of paediatrics In the others the diagnosis is made by the senior surgeon or his assistants

If a case of CDH is suspected at any one of these hospitals and referred to us and we cannot elicit a clicking sound by forced abduction roentgenographic confirmation or exclusion of the condition would

require attempted dislocation of the hip a procedure we consider inadvisable We therefore decided to rely on the diagnosis made at the local hospital even if we cannot verify the click and to place the child in an abduction frame for 6 weeks According to our radiologists (Dr Norman) the first roentgen examination should be made when the child is 4–5 months old The ossification centres of the proximal femora are then readily recognized and the roentgen examination offers no difficulties

Since 1961 the following scheme has been used

1 Examination of all newborns for CDH by the paediatrician or the surgeon in charge of the maternity ward

2 Prompt transfer of all infants with suspect CDH to the department of Orthopaedics Lasarettet Lund for examination by an experienced orthopaedic surgeon

3 Irrespective of the clinical findings the child is placed in an abduction frame (von Rosen or modified type)

4 Re examination 3 weeks later to check that the frame is properly applied and that the mother is co operating

5 After a further 3 weeks removal of the frame and clinical examination of the hips

6 Roentgen examination of the hips

a) when the child is 4–5 months old

b) again when the child is 1 year old or has begun to walk and then

c) again one year later

We have found this scheme satisfactory *It appears that all these children have developed normal hips although some of them were less than one year of age at the follow up No child born in the county of Malmohus during the years 1961–1964 has appeared at about the age of one with a subluxated or luxated hip*

It is obvious that our scheme carries a certain risk of overdiagnosis especially if the examiner is less experienced Our material consists of 63 patients (41 from the maternity department Lasarettet Lund 3 from Trelleborg 12 from Landskrona 2 from Ystad and 5 from Horby)

The clinical diagnosis was said to be *confidential* or certain when the examiner at the orthopaedic department in Lund could elicit a click on forced abduction of the hips Otherwise it was said to be uncertain

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While this paper was being prepared for the press however one case was missed in a child born in January 1965 This case will be the subject of a separate paper

The discrepancy between the results of the primary examinations and the re-examination at Lund can be explained by several factors, particularly by the difference in the age of the children at the time of the *two examinations*. Thus the *average* age of the children in whom the diagnosis was *confidential* was 2.4 days, compared with 6.4 days for those in whom the diagnosis was uncertain (Table 1). This is in accord with the finding by *Andren & Borglin* that the pubic pelvis becomes stable and the hormone balance normal on the fifth or sixth day of life. The diagnosis of CDH was *confidential* in 36 children. Of these 27 had been born in Lund, 1 in Trelleborg, 1 in Horby and 7 in Landskrona (Table 2).

*Table 1. Mean age (days) of patients on arrival at the outpatient department of the orthopaedic department for treatment in a frame*

| Places of birth | Lund | Landskrona | Trelleborg | Ystad | Horby | The whole material |
|---|---|---|---|---|---|---|
| Uncertain dislocations | 3.5 | 5 | 2.5 | 13 | 12.5 | 6.4 |
| Certain dislocations | 1.5 | 5 | 6 | – | 7 | 2.4 |

*Table 2. Places of birth and number of certain and uncertain dislocation 1961–1964*

| Hospital in the town of | Lund | Landskrona | Trelleborg | Ystad | Horby |
|---|---|---|---|---|---|
| Number of uncertain dislocations | 14 | 5 | 2 | 2 | 4 |
| Number of certain dislocations | 27 | 7 | 1 | 0 | 1 |
| Total | 41 | 12 | 3 | 2 | 5 |

During the last 4 years the frequency of diagnosed CDH has varied widely (Table 3). We can offer no explanation for this variation. Since no cases in the district covered by Lund or the aforementioned small hospitals have been referred to other large hospitals, e.g. Malmö and Helsingborg, the cases seen at Lund must be representative of the entire district catered for by the Lasarettet, Lund. The patients' ages at the time of admission to the orthopaedic department in Lund are given in Table 4.

*Table 3 Number of cases of dislocation of the hip in the district of Malmohus excluding the towns of Malmo and Halsingborg*

| Year of birth | Clinically uncertain | Clinically certain |
|---|---|---|
| 1961 | 9 | 12 |
| 1962 | 7 | 6 |
| 1963 | 5 | 12 |
| 1964 | 6 | 6 |

*Table 4 Children's age (days) at first examinations at the department of orthopaedics in Lund*

| Age in days | <1 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 12 | 13 | 16 | 20 | 23 | 25 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Number of uncertain dislocations | 5 | 0 | 6 | 3 | 2 | 2 | 2 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Number of certain dislocations | 3 | 12 | 8 | 5 | 2 | 2 | 2 | 1 | 1 | – | – | – | – | – | – | – |

Table 4 shows that 28 out of 36 children with certain CDH were examined within the first 3 days of life. Concerning children with uncertain CDH it appears that spontaneous reposition can occur within the first week of life or that it is very difficult to diagnose after this age or that there is an overdiagnosis.

The frequency with wich the condition is diagnosed at the various hospitals is given in Table 5, from which it is obvious that in the small hospitals this frequency is low. Since the condition may be easily missed, we think that a certain overdiagnosis is justified, especially in small hospitals. This is why we treat all children with suspect CDH in a frame whether later check examination by the orthopaedic surgeon can produce Ortolani's click or not.

## SUMMARY

Since 1961 all newborns referred to the Department of Orthopaedics Lasarettet, Lund because of suspect congenital dislocation of the hip are placed in an abduction frame for 6 weeks whether Ortolani's click can be produced or not on admission to our department. In other words we rely on the result of the primary examination soon after birth even

*Table 5.* Number of viable infants born at 5 Scanian hospitals and number of certain and uncertain cases of dislocation of the hip

| | Lund | | | Landskrona | | | Trelleborg | | | Ystad | | | Horby | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Number of viable infants | Certain disloc. | Uncertain disloc. | Number of viable infants | Certain disloc. | Uncertain disloc. | Number of viable infants | Certain disloc. | Uncertain disloc. | Number of viable infants | Certain disloc. | Uncertain disloc. | Number of viable infants | Certain disloc. | Uncertain disloc. |
| 1961 | 2 633 | 10 | 6 | 401 | 0 | 0 | 390 | 1 | 2 | 277 | 0 | 0 | 188 | 1 | 1 |
| 1962 | 2 670 | 5 | 3 | 488 | 1 | 1 | 352 | 0 | 0 | 278 | 0 | 1 | 121 | 0 | 2 |
| 1963 | [illegible] | 8 | 3 | 510 | 4 | 1 | 480 | 0 | 0 | [illegible] | 0 | 0 | 128 | 0 | 1 |
| 1964 | [illegible] | 4 | 2 | 528 | 2 | 3 | 473 | 0 | 0 | 283 | 0 | 1 | 45 | 0 | 0 |

though it may mean a certain degree of overdiagnosis As far as we know from 1961 to the end of 1964 no cases of CDH have escaped detection and treatment

## RESUME

Depuis 1961 tous les nouveau nés envoyés au Service Orthopedique de l hopital de Lund parce qu on soupconnait chez eux une dislocation congenitale de la hanche ont ete places dans un cadre d abduction pendant six semaines qu il ait ete possible de produire ou non le ressaut Ortolani a leur admission dans notre Service En d autres mots nous fondons sur le résultat de l examen primaire immediatement apres la naissance bien qu il puisse s agir d un certain degré d un superdiagnostic Pour autant que nous le sachions de 1961 a la fin de 1964 aucun cas de dislocation congenitale de la hanche n a echappe a notre attention et au traitement

## ZUSAMMENFASSUNG

Seit 1961 werden alle Neugeborenen die an das orthopadische Lazarett in Lund wegen Verdacht auf kongenitale Huftverrenkung gewiesen werden in einen Abduktionsrahmen fur 6 Wochen gelegt gleichgultig ob das Ortolanische Zeichen bei der Aufnahme an unsere Abteilung nachgewiesen werden kann oder nicht Mit anderen Worten wir verlassen uns auf die primare Untersuchung gleich nach der Geburt obwohl das einen gewissen Grad von Uberdiagnose bedeuten kann So weit wir wissen ist von 1961 bis Ende 1964 kein Fall von angeborener Huftverrenkung unentdeckt oder unbehandelt geblieben

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# HIP JOINT ARTHRODESIS
# TO FIND THE BEST POSITION

By

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Received 7 ii 66

Since a hip joint arthrodesis implies that the hip is to be immobilized in a certain position for the rest of the patient s life it would seem incumbent on the surgeon to ensure that the position decided upon is the best possible But at this point a theoretical and a practical problem are encountered namely what is the best position and how can it be obtained at the operation In this paper these problems are discussed and bases for their solution are proposed

## THE THEORETICALLY BEST POSITION

In an earlier paper *Ahlbäck & Lindahl* (2) have examined closely the positions in the transverse frontal and sagittal planes that have been preferred by various authors On the basis of a follow up examination of hip arthrodesis cases *Ahlbäck & Lindahl* themselves recommended the following positions in the transverse plane slight outward rotation in the frontal plane in or near the neutral positions (5) and in the sagittal plane about 45 flexion counted from an initial position in maximum extension (*Ahlbäck & Lindahl* (1)) For the joint to be fixed in such marked flexion it is essential for the spinal mobility to be great enough and the direction of motion to be correct

The significance of these two factors is considered in this paper

## PREOPERATIVE EXAMINATION

In the pre operative analysis of the most suitable position the following examinations are necessary

1 Examination to establish whether an outward rotation contracture prevents the leg from being immobilized with an outward rotation of 10–30 It is acceptable if the leg can be positioned between these limits if not the advisability of resorting to surgical measures to achieve this must be considered Usually however the patient is satisfied with any outward rotation position that is not too extreme

2 A radiological examination to find whether there is any real shortening of the leg A determination of the actual length of the leg is essential if the neutral position is to be found and the leg is to be arthrodesed in this position in the frontal plane (5)

3 Examination to ascertain whether the leg is so mobile in the frontal plane that it can be set in the neutral position If there is an adduction contracture which precludes this position the advisability of adductor tenotomy to achieve it must be considered As a rule the mobility increases slightly under anaesthesia and the required position may then be attainable

4 Examination of the total sagittal range of mobility of both hip joints The method has been described elsewhere (1)

5 Examination of the total sagittal range of mobility of the lumbar spine (L) An account of the method has been published (6)

6 Measurement of the angle between the thoracic spine and the rigid thigh ($Th_eT_r$) with maximum extension in both the lumbar spine and the hip

## MECHANICS OF SAGITTAL MOBILITY OF LUMBAR SPINE AND HIP JOINTS

In a theoretical analysis to find the most suitable position account must be taken of the dependence of various functions (sitting comfort and length of pace) on certain initial conditions (range of mobility angles) in the choice of arthrodesis angles in the sagittal plane

To facilitate description of the involved trigonometrical relationships the following terminology and abbreviations will be used

*Fore pace (F)* The pace taken with the rigid leg forward

*Rear pace (R)* The pace taken with the mobile leg forward

*ThT* Angle between the thoracic spine and one thigh

$Th_eT_a$ The angle *ThT* with the lumbar spine fully extended and the thigh in the position for arthrodesis

$Th_eT_m$ The angle *ThT* in full extension of the lumbar spine and the mobile thigh with the hip joint extended

$Th_eT_r$ The angle $ThT$ with full extension of the lumbar spine and the rigid thigh in maximum extension

$S$ Sitting angle the angle between the thoracic spine and the rigid thigh in full flexion of the lumbar spine

$L$ Range of mobility of the lumbar spine from full extension to full flexion

$H_f$ Flexion angle for the hip joint measured from normal full extension (1)

To simplify the analysis the following assumptions may be made (with other assumptions the analysis will take a different form)

1 A pace with an angle of 40 between the two legs is acceptable for a person with an arthrodesis (the normal pace is slightly longer 50 )

2 If for some reason one of the steps must be shorter than normal it is of minor importance whether it is the fore or the rear pace that is shortened After arthrodesis the fore pace will usually be the shorter one

3 In the ordinary seated position the angle $S$ ranges from 90 to 135 (in the latter extreme there is a backward inclination of the lumbar spine) For an arthrodesis patient an angle of 135 is acceptable but sitting will be more comfortable if it is about 115

Table 1 shows the fore and the rear paces obtained with different values of $Th_eT_m$ and the arthrodesis angle $Th_eT_a$ The sitting angles are given for different lumbar spinal mobility ranges from 65 down to 45

An angle $Th_eT_m$ of 120 is found at lower ages and corresponds usually to a good spinal mobility in these cases the direction of motion is usually suitable for the hip arthrodesis It is seen in the table that for the arthrodesis positions with large flexion angles the ranges of mobility are good for both paces A flexion position of about 50 would seem to be optimal—possibly larger for a person with a sedentary occupation (Figure 1) With a small flexion angle such as 30 sitting is less comfortable and there is no improvement in the length of pace if both paces are considered

A number of persons quite normally adopt a slight stoop when walking and many with arthrodesis have the same posture apparently without discomfort It would therefore seem natural to accept a slight forward inclination of the thoracic spine—say about 20 —as the rear pace is being taken since this considerably lengthens the step The acceptance of such a gait will bear on the choice of arthrodesis position

*Table 1 Relationship between fore pace (F) rear pace (R) sitting angle (S) and arthrodesis angle ($Th_eT_a$) for various thoracic spine—thigh angles for the mobile thigh ($Th_eT_m$) and various ranges (65 55 and 45 ) of lumbar spine mobility (L) B/20 denotes the length of the rear pace for a forward inclination of 20 of the thoracic spine $H_f$ is the flexion in the hip joint in the planned arthrodesis position The figures in italics are the recommended combinations*

| $Th_eT_m$ | $Th_eT_a$ | $H_f$ | F | R | B/20 | S L 65 | S L 55 | S L 45 |
|---|---|---|---|---|---|---|---|---|
| 120 | 180 | 60 | 60 | 0 | 40 | 115 | 125 | 135 |
| 120 | 170 | 50 | 50 | 20 | 60 | 125 | 135 | 145 |
| 120 | 160 | 40 | 40 | 40 | 80 | 135 | 145 | 155 |
| 120 | 150 | 30 | 30 | 60 | 100 | 145 | 155 | 165 |
| 120 | 140 | 20 | 20 | 80 | 120 | 155 | 165 | 175 |
| 130 | 180 | 50 | 50 | 0 | 40 | 115 | 125 | 135 |
| 130 | 170 | 40 | 40 | 20 | 60 | 125 | 135 | 145 |
| 130 | 160 | 30 | 30 | 40 | 80 | 135 | 145 | 155 |
| 130 | 150 | 20 | 20 | 60 | 100 | 145 | 155 | 165 |
| 130 | 140 | 10 | 10 | 80 | 120 | 155 | 165 | 175 |
| 140 | 180 | 40 | 40 | 0 | 40 | 115 | 125 | 135 |
| 140 | 170 | 30 | 30 | 20 | 60 | 125 | 135 | 145 |
| 140 | 160 | 20 | 20 | 40 | 80 | 135 | 145 | 155 |
| 140 | 150 | 10 | 10 | 60 | 100 | 145 | 155 | 165 |
| 140 | 140 | 0 | 0 | 80 | 120 | 155 | 165 | 175 |
| 150 | 200 | 50 | 50 | a | 0 | 95 | 105 | 115 |
| 150 | 190 | 40 | 40 | b | 20 | 105 | 115 | 125 |
| 150 | 180 | 30 | 30 | 0 | 40 | 115 | 125 | 135 |
| 150 | 170 | 20 | 20 | 20 | 60 | 125 | 135 | 145 |
| 150 | 160 | 10 | 10 | 40 | 80 | 135 | 145 | 155 |
| 160 | 200 | 40 | 40 | a | 0 | 95 | 105 | 115 |
| 160 | 190 | 30 | 30 | b | 20 | 105 | 115 | 125 |
| 160 | 180 | 20 | 20 | 0 | 40 | 115 | 125 | 135 |
| 160 | 170 | 10 | 10 | 20 | 60 | 125 | 135 | 145 |
| 160 | 160 | 0 | 0 | 40 | 80 | 135 | 145 | 155 |
| 170 | 200 | 30 | 30 | a | 0 | 95 | 105 | 115 |
| 170 | 190 | 20 | 20 | b | 20 | 105 | 115 | 125 |
| 170 | 180 | 10 | 10 | 0 | 40 | 115 | 125 | 135 |
| 170 | 170 | 0 | 0 | 20 | 60 | 125 | 135 | 145 |
| 180 | 200 | 20 | c | a | 0 | 95 | 105 | 115 |
| 180 | 190 | 10 | d | b | 20 | 105 | 115 | 125 |
| 180 | 180 | 0 | 0 | 0 | 40 | 115 | 125 | 135 |

*a* Cannot be performed without forward inclination of more than 20

*b* , 10

*c* Maximum 20 possible when forward inclination will be 10

*c* 5

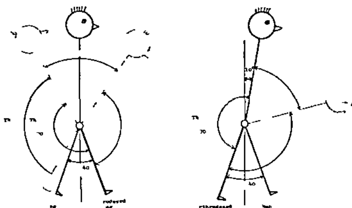


*Figure 1* *Diagram illustrating sagittal movements of the lumbar spine and mobile hip in an arthrodesis case The conditions are Th* $T_m$ *120 L 65 and Th* $T_a$ *170 Both F and R have been made 40 F can be 50 if the mobile hip is extended to position E R requires a forward inclination of the upper trunk of 10 If this is increased to 20 the pace can be 60 The sitting angle S will be quite comfortable (125 )*

The length of the rear pace when the upper trunk is inclined 20 forwards is given under $B$ 20

An angle $Th_eT_m$ of 140 is probably quite common at ages at which arthrodesis are usually performed and at 40–60 years it is normally about 145 (6) It is seen here that an arthrodesis set with a small angle of flexion results in not only a less comfortable seated position but also a shorter fore pace while the rear pace will be unnecessarily long and will not be fully exploited For this group an arthrodesis position with 30–40 flexion would seem optimal for the arthrodesis

As $Th_eT_m$ is increased further (160 ) so is the difficulty of obtaining a good length of pace but a comfortable sitting position is more easily achieved Here a flexion of only 20–30 is perhaps to be preferred

When $Th_eT_m$ is as large as 180 a pathological condition also of the mobile hip joint may be suspected and the chance of obtaining a good length of pace is yet more slender though a comfortable seated position is still reasonably certain For such cases extension or slight flexion (10 ) may be best for the arthrodesis (Figure 2)

Since the flexion contracture will probably be larger for the affected than the mobile hip ($Th_eT_r$ is almost invariably greater than $Th_eT_m$) there may be difficulty in achieving the desired position

The discussion has been limited so far to the size of $Th_eT_m$ and its effect on the length of pace for various arthordesis positions A reduc

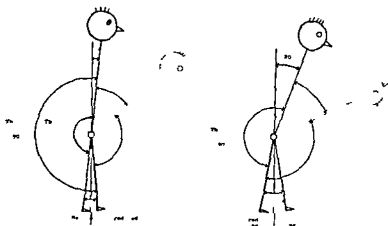


*Figure 2 Diagram illustrating the sagittal movements of the lumbar spine and mobile hip in an arthrodesis case The conditions are $Th_eT_m$ 180 L 45 and $Th_eT_a$ 170 F will then be only 10 with a forward inclination of the upper trunk of 5 If the forward inclination is 20 R will be 20 The paces will be short but the sitting angle S will be quite comfortable (125 )*

tion in the range of mobility of the lumbar spine as often occurs in these cases must also be taken into account in deciding the arthrodesis position

If the range of lumbar spine mobility is not below 45 —when a hip arthrodesis would probably not be very suitable—there is no risk that the reduction in mobility will restrict either pace On the other hand the comfort in sitting is reduced when the mobility of the lumbar spine decreases If a maximum of 135 for *S* is taken as providing an accept able level of sitting comfort the choice of suitable arthrodesis positions is considerably restricted when the spinal mobility is reduced and then the more flexed positions are preferable

For an analysis of the relationship between the various functions on the basis of other conditions and other angles the following relation ships may be used

$S = 360 - Th_eT_a - L$
$F = Th_eT_a - Th_eT_m$ provided that $Th_eT_a \leq 180$ and $Th\ T_m < 180$
$R = 2\ (180 - Th_eT_a)$
$H_f = Th_eT_a - Th_eT_m$ provided that the extension in the better hip is considered to be normal

## PREOPERATIVE EVALUATION

*Without entering on a trigonometrical analysis in the individual case* it is possible to form an opinion on the most suitable arthrodesis angle

from an examination of the patient and the data in Table 1 The data required are the total sagittal range of mobility ($L$–6a $L$–5a and $L$–4a in the table) and the angle between the thoracic spine and the mobile thigh in full extension of both the lumbar spine and the hip ($Th_eT_m$ in the table) From these values the size of the fore and the rear paces and the sitting angle (F R and S) can be found If one accepts a rear pace with a forward inclination of 20 when the pace is made its size will be found under B'20 A certain arthrodesis angle can then be decided upon ($Th_eT_a$ or $H_f$) that gives values that will apparently be optimal for the patient with due regard to such factors as his occupation and sitting habits It must also be checked whether this position lies within the limits for the range of mobility of the rigid hip If this is not the case it is necessary to consider as in the case of outward rotation contracture or adduction contracture whether surgical measures must be resorted to in order to free the rigid hip so that the required position can be achieved

## OPERATING TABLE AND TECHNIQUE

To realise a planned arthrodesis angle there are certain practical requirements Although from a theoretical aspect a number of surgical methods may be used it would seem to be most easily performed by a nail arthrodesis on an extension operating table so as get the hip into the exact position To obtain healing of the bone a graft combined with drilling through the joint is recommended Methods requiring initial dislocation of the hip removal of cartilage and shaping of the femoral head and acetabulum after which the hip joint is repositioned call for such extensive manoeuvres of the leg that it is difficult if not impossible to make the necessary measurements on the patient under aseptic conditions and to obtain the desired position

The operating table should permit rotation of the leg about its axis and abduction and adduction in both legs A combined abduction and adduction of both hip-joints is often best obtained by extending one leg and applying pressure to the other and such a movement must therefore be feasible For positioning in the frontal plane it must be possible to indicate both malleoli and to determine the centre of the mobile hip This is best done by fluoroscopy with for instance X ray television when the centre of the femoral head can easily be marked on the skin in the region of the groin

To be able to position the hip-joints and spine in the sagittal plane

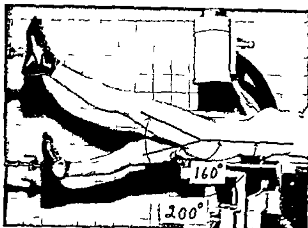



*Figure 3* Operating table with the patient in position for an arthrodesis $Th\,T_m$ is 160 $Th_e T_a$ 200 and $H_f$ 40

it must be possible for both legs to be raised and lowered through an angle of at least 40°

## PRE OPERATIVE SETTING OF THE HIP JOINT

First the leg is set in a suitable rotation position (for instance 15 out ward rotation) Since there is a certain rotation in the knee also in the extended position (*Hallen & Lindahl* (3)) and there is a large rotation in the foot the required rotation position should be checked on the patella

The position in the frontal plane is then achieved by traction and pressure in the axial direction of the legs so as to bring both ankles to the same distance from the centre of the mobile hip If the real shorten ing is more than 1 cm it may be necessary to compensate for it and to secure the neutral position (5) to avoid tipping of the pelvis in the standing position

The saggittal position is then obtained First full extension of the mobile hip and lumbar spine is achieved by lowering the mobile leg (the angle $Th_e T_m$ is then obtained between the thorax and this thigh Figure 6 A page 247 in article with reference No 6) The rigid thigh is then placed in the determined flexion position ($Th_e T_a$) and the angle between the thoracic spine (plane of the operating table) and the rigid hip is measured When this position has been achieved a new check should be made in the frontal plane in which there may have been a change during these manipulations (Figure 3) The position so obtained is retained throughout the operation

## DISCUSSION

The performance of a theoretical analysis followed by attainment of the desired position might appear an involved procedure for an arthrodesis and one may wonder whether so great an apparatus is necessary

In many cases the hip has been set naturally in a more or less ideal flexion position through a flexion contracture of 30–40 (note the difference between the angle obtained by Thomas s test and the true flexion contracture (1)) and in these cases the required flexion position is obtained only by allowing the patient to lie on a plane operating table with the lumbar spine slightly lordosed through the weight of the thigh Whether this actually happens can be found by the procedure described and it is then unnecessary to make any major arrangement at the operation In these cases *Watson Jones* (7) words are perhaps relevant "As the patient lies on the table there is enough lordosis to be sure that the final position of consolidation will amount to only 30 degrees of fixed flexion which is quite enough for comfortable sitting and is correct for comfortable standing In a fair number of cases however these conditions are not present and it would seem that an analysis and more exact positioning are essential if the patient s potential mobility is to be realized by the operation

Since the patient himself is almost invariably satisfied because his pain has been banished (4) and since he will not know which position would be better one need not in such a case take a satisfied patient as a mortgage to realize the best possible result

## SUMMARY

In the performance of a hip-joint arthrodesis there are two problems in addition to that of the surgical technique namely which position of the hip will give the best function and how this is to be realised at the operation On the basis of a trigonometrical analysis of the sagittal mobility of the hip joints and lumbar spine an account is given in tabular form of the relationship between certain ranges of mobility measured before the operation and the postoperative function with different arthrodesis angles The positioning in the frontal and transverse planes has been discussed in earlier papers After a pre operative analysis of the "best arthrodesis angle a method is presented for achieving this position at the operation

The need for such a careful procedure is discussed

### RESUME

Lorsqu'on procède à une arthrodèse de la hanche il faut tenir compte en plus de la technique chirurgicale de deux problèmes à savoir quelle position de la hanche donnera la meilleure fonction et comment cell ci peut être realisée par l'opération. Sur la base d'une analyse trigonometrique de la mobilite sagittale des articulations de la hanche et de la colonne lombaire un compte redu est donné sous forme de tableau de la relation entre certaines etendues de mobilite mesurees avant l'operation et la fonction post operatoire avec differents angles d'arthrodeses. La mise en position dans le plan frontal et transversal a été discutée dans des publications antérieures. Après une analyse pre opératoire du meilleur angle d'arthrodèse une methode a eté presentée pour l'établissement de la position par l'operation.

*Le besoin d'une procedure minutieuse de ce genre est discuté*



### ZUSAMMENFASSUNG

Bei der Ausführung einer Huftgelenksarthrodese sind abgesehen von der chirurgischen Technik zwei zusatzliche Probleme vorhanden nämlich – welche Stellung wird die beste Funktion ergeben und wie kann man dies unter der Operation klarlegen. Auf Grundlage einer trigonometrischen Analyse der sagittalen Beweglichkeit der Hüftgelenke und der Lendenwirbelsaule wird in tabellarischer Form ober die Beziehung zwischen gewissen vor der Operation gemessenen Bewegungsbereichen und der postoperativen Funktion bei verschiedenen Arthrodesewinkeln berichtet. Die Einstellung in der frontalen und transversen Ebene ist in einer fruheren Arbeit besprochen worden. Nach einer praoperativen Analyse des besten Arthrodesewinkels wird eine Methode zur Erhaltung dieser Position wahrend der Operation mitgeteilt.

Die Notwendigkeit eines derartigen sorgfaltigen Vorgehens wird besprochen


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# TRIPLE ARTHRODESIS OF THE TARSUS AS A TREATMENT FOR POSTTRAUMATIC CONDITIONS

*By*

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Received 14 xii 65

Triple arthrodesis of the tarsus is one of the most common operations in orthopaedic surgery It is valuable in correcting deformities and stabilising the foot after paralytic conditions but also in the treatment for painful post traumatic conditions of the foot and ankle

The fractures which most often tend to cause osteoarthritis and pain in the subtalar region are fractures of the calcaneus and talus less often the malunited malleolar fractures

Despite the fact that triple arthrodesis is such a common procedure surprisingly few reports on follow up examinations have been published *Lindholm* (1960) has published the late results of triple arthrodesis in the treatment of paralytic ankle performed in the orthopaedic hospital of the Invalid Foundation In 1959 *Skobowytsh Okolot* reported the results of triple arthrodesis in 80 patients of which 15 were paralytic cases *Thompson & Friesen* (1959) reported the results of primary triple arthrodesis in 25 cases as the treatment of comminuted calcaneus fractures In their material the result was good or excellent in 24 cases Primary arthrodesis was also recommended by *Trojan* (1961) though *Dewar* (1959) noted no difference in the late results of 153 calcaneus fractures treated conservatively or by primary triple arthrodesis The purpose of the present report is to estimate the late results achieved by triple arthrodesis in the treatment for different painful post traumatic conditions of the ankle when the operation has been performed several years after the primary conservative treatment of the fracture The patients were admitted to the hospital of the Invalid Foundation Helsinki from different parts of Finland

## MATERIAL AND METHODS

The material includes all patients who from July 1956 to June 1963 were treated by triple arthrodesis for painful conditions after fractures in the ankle region The number of patients operated during this period was 32 of whom 24 were men and 8 women Of the patients 24 were insured against accidents and 8 were uninsured

The age of the patients at admission to the hospital can be seen in Table 1

*Table 1*

| | |
|---|---|
| Under 20 years | 3 patients |
| 20–29 | 1 " |
| 30–39 | 10 " |
| 40–49 | 8 " |
| 50 years or more | 10 " |
| Total | 32 patients |

The youngest patient was aged 15 and the oldest 62 The dominant indication for the operation was pain caused either by osteoarthritis which appeared in the sub talar joints or pain caused by the deformity in itself especially in young patients The original injury was in most cases either fracture of the calcaneus or talus or malunited bimalleolar fracture The nature of the primary fracture may be seen in Table 2

*Table 2*

| | |
|---|---|
| Fracture of the calcaneus | 11 patients |
| Fracture of the talus | 2 " |
| Bimalleolar fracture | 8 |
| Late sequels of gunshot fracture | 11 " |
| Total | 32 patients |

The gunshot fractures were naturall open fractures and resulted almost without exception in suppuration of the fractured area

Arthrodesis was performed by removing articular cartilage from the talo-calcaneal the talo-navicular and the calcaneo cuboidal joints after which the denuded bone surfaces were pressed together In most cases internal fixation was not used In some cases where an especiall large correction was performed Blount s vitallium staples were used to fix the talus and the calcaneus together The time of immo bilization in plaster was in all cases 4 months During the first month no weight bearing was allowed but during the following three months full weight bearing was ordered in a walking plaster boot In only one case did a disturbance of post operative development occur This was a slight skin necrosis at the edges of incision but it healed before the end of the immobilization period without any special treatment

A fact which atracted our particular attention was that the interval between primary injury and arthrodesis was in 15 cases 1 3 years while in 17 cases it was over 10 years Intervals of 3–10 years between fracture and arthrodesis were not noticed in this material It seems obvious that in some cases pain continues after consolidation of the fracture whereas in others a painless period is gradually followed by osteoarthritis and pain

## RESULTS OF THE FOLLOW UP EXAMINATION

The follow up examination was carried out at the beginning of 1964 It appeared that bony anchylosis was achieved in all cases except in one in which the Chopart joint developed fibrous union The patient complained of pain on walking The result was recorded as good both subjectively and objectively in 26 patients In one of the six remaining patients there was a varus deformity in the foot and the patient had pain on walking In 5 cases the position of the foot was good, but the patients complained of pain on prolonged walking One of these was the patient whose Chopart joint was not consolidated Another had a slight swelling of the ankle and osteoarthritis also in the talocrural joint after a bimalleolar fracture Not a single patient complained of instability or difficulty in walking on uneven ground

All 26 patients in whom the resul of treatment was uniformly suc cessfull returned to the same work as they had before the operation Of the 6 in whom weight bearing caused pain 5 also returned to their former work Only one did not resume work Objectively no reason could be found for the inability to work but the patient himself con sidered that the pain of weight bearing made work impossible It seems obvious that the fear of reduced insurance compensation was the most pressing reason for the inability to work in this case

The results of this follow up examination confirm the opinion that triple arthrodesis is a suitable and effective treatment for painful con ditions after fractures in the region of the ankle if the pain is in the subtalar joints It was not possible to draw any conclusions whether arthrodesis as a primary treatment would have been preferable to con servative treatment since all patients had received their primary treat ment in different general hospitals For this reason it was also im possible to analyse the nature of the primary fracture or its role in the pain appearing later in the subtalar joint

## SUMMARY

The authors report the results of a follow up examination of 32 patients in which triple arthrodesis of the tarsus was performed to relieve pain or to correct deformity after different fractures in the ankle region The most dominant indication for operation was pain after fracture of the calcaneus or the talus or after bimalleolar fracture Bony anchylosis of the subtalar joints was achieved in 31 cases In one case the Chopart joint did not consolidate The result was recorded as good both accord

ing to the patient s subjective estimate and according to the position of the foot in 26 patients All these returned to their preoperative occu pation Five patients had pain on walking but not enough to prevent them from working One patient did not resume work and the reason for this was considered to be the fear of reduced insurance compensa tion since no objective reason for this inability was discovered

## RESUME

Les auteurs rapportent les resultats d un examen complémentaire de 32 malades chez lesquels a été pratiquee une triple arthrodese du tarse pour soulager de douleurs ou pour redresser une deformite apres dif ferentes fractures dans la region de la cheville L indication dominante pour l operation a ete des douleurs apres une fracture du calcaneum ou du talus ou encore apres une fracture bimalléolaire L ankylose osseuse des articulations sub talaires a eté pratiquee dans 31 cas Dans un cas l articulation Chopart ne s est pas consolidee Le resultat en registre a ete bon selon l appreciation subjective des malades et selon la position du pied chez 26 malades Tous ceux ci ont repris leurs occupations anterieures Cinq malades avaient des douleurs a la marche mais pas suffisamment pour les empecher de travailler Un malade n a pas repris son travail par crainte semble t il d une reduction de l indemnite à verser par l assurance Il n a en effet pas eté possible de decouvrir une raison objective a cette incapacite de travail

## ZUSAMMENFASSUNG

Die Verfasser berichten uber die Ergebnisse einer Nachuntersuchung von 32 Patienten an denen eine Triplearthrodese des Tarsus ausgefuhrt worden war um Schmerzen zu erleichtern oder Deformiteten nach ver schiedenen Bruchen in der Knochelregion zu korrigieren Die Haupt anzeige zur Operation war Schmerzen nach Calcaneus oder Talusbruch oder nach bimalleolaren Bruchen Knocherne Ankylose des subtalaren Gelenkes wurde in 31 Fallen erzielt In einem Falle kam es nicht zur Konsolidierung des Chopart Gelenkes Das Ergebnis wurde sowohl gemäss der subjektiven Angabe des Patienten als auch gemäss der Eussstellung bei 26 Patienten als gut klassifiziert Alle diese kehrten zu ihrer voroperativen Beschaftigung zuruck Funf Patienten hatten Schmerzen beim Gehen doch nicht so stark dass sie am Arbeiten verhindert waren Ein Patient arbeitete nicht mehr doch nahm man an dass der Grund dafür Furcht vor einer Herabsetzung der Unfalls

rente war da keine objektive Ursache fur seine Arbeitsunfahigkeit zu entdecken war

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# GRADING OF OSTEOPOROSIS ON BIOPSY SPECIMENS

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Received 7 II 66

The term osteoporosis has been defined in a variety of ways and is used to denote both disorders of the back and the gross or microscopic alterations of the actual bone *Lindahl & Lindgren* (3) have discussed these definitions and on the basis of a determination of the apparent density of the spongiosa in vertebrae and the tibia they have defined osteoporosis as a value of less than 0 20 mg per mm³ for the apparent density of the spongiosa of the tibial epiphysis As the apparent density is a direct measure of the porosity of the substance examined this definition would seem to be most consistent with the etymologic meaning of the term osteoporosis The border between what can be regarded as normal and pathologic has been put at 0 20 because for almost all the group of young subjects in sound health the apparent density was above this figure (the mean was 0 30) This limit is of course arbitrary and because of the gradual reduction in the apparent density with age what is conceived as normal will depend on the age of the patient

The study and the definition were based on a large autopsy series where large parts of the spongiosa could be removed and subjected to examination

In the present paper a method is presented for determining the apparent density for the individual patient on the basis of a bone biopsy examination

## METHOD

Since the density determinations on spongiosa in the previous study were performed on spongiosa from the upper epiphysis of the tibia about 5 cm from the articular face this site was chosen for the bone biopsies

The patients in whom osteoporosis was suspected or confirmed by radiography

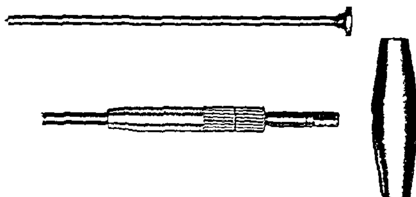


*Figure 1 Bone biopsy instrument with mandrin needle and handle*

were anaesthesized with 1 per cent lidocain with Exadrin deposited on the medial surface of the tibia about 5 cm below the articular space A longitudinal incision 2 cm in length was made through the skin and periosteum which was scraped away over an area about 1 cm in diameter A special biopsy needle (Figure 1) was then inserted perpendicular to the bone surface usually to a depth of 25 mm This stage of the operation sometimes caused a little pain since the spongiosa is not reached by the anaesthetic So that the specimen should be removed with the needle this was moved slightly in various directions before withdrawal The specimen was removed from the needle with a mandrin and the wound was closed with a suture

Specimens were obtained in this way in some 80 cases without complications Sometimes there was no discomfort after the specimen had been removed but quite often there was pain and swelling in the region for up to a week

## THE NEEDLE

The needle has outer and inner diameters of 6 and 5 mm respectively The teeth were quite large and set so that the needle could be withdrawn fairly easily and the bone specimen would accompany the needle Small deviations in the setting at first gave rise to difficulty in both these respects To determine the depth and hence the volume of the specimen the needle was furnished with an outer collar which could be adjusted on a graduated scale A depth of 25 mm was generally used which gives a specimen volume of 491 mm$^3$

As the specimen is quite firmly attached to the needle especially if the bone is normal it will not infrequently be compressed when expelled from the needle with the mandrin

The needle being of fairly large calibre there is sometimes initial difficulty in getting it to hold because it is displaced to the side To avoid this the mandrin was inserted so as to be in place during the first part of the drilling through the cortical bone The mandrin has a point in the centre which prevents lateral displacement

## DETERMINATION OF THE APPARENT DENSITY

Because in the next stages of the preparation of the specimen it tends to break up into small pieces it was enclosed in gauze from the outset This was first flushed with hot water to remove blood and fat and then dried overnight at 100 C The residual fat was extracted with xylene for 24 hours in two stages and the specimen was then dried again for 24 hours at 100 C It was weighed immediately it was taken from the drying oven at this stage the specimen is hygroscopic and rapidly takes up atmospheric moisture

The quotient of the weight so found and the original volume gives the apparent density

## RESULTS ON SUBJECTS

In 10 cases of radiological or suspected osteoporosis determinations of the apparent density were performed as outlined above At the same time the hardness of the bone judged as the resistance to drilling was estimated according to a four degree scale The results are given in Table 1 The hardness tended to increase with the apparent density

*Table 1 Apparent density for 10 cases of radiological or suspected osteoporosis determined by the bone biopsy method The hardness was estimated according to a 4 degree scale*

| Subject | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| Apparent density | 0.10 | 0.10 | 0.12 | 0.13 | 0.15 | 0.15 | 0.18 | 0.22 | 0.23 | 0.29 |
| Hardness | 1 | 2 | 2 | 2 | 3 | 2 | 2 | 3 | 4 | 4 |

## COMPARISON OF THE OLD AND NEW METHODS

Since there was no way of assessing the reliability and accuracy of the method on the living subject repeated determinations of the apparent density with the biopsy needle were performed on 10 autopsy cases the specimens being taken from adjacent areas and determinations

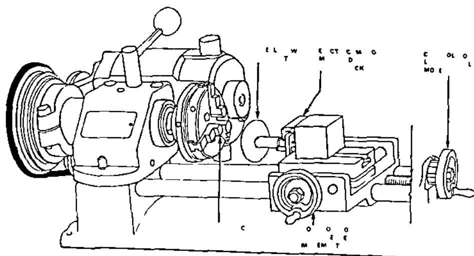


*Figure 1 Bone cutting apparatus The embedded bone is not shown*

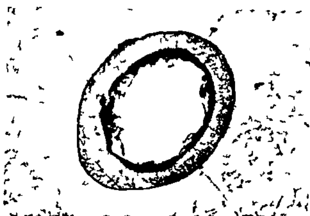


*Figure 2 Photomicrograph of a section of rat femur prepared by the technique described (Magnification × 25)*

water Sections as thin as 100 μ are obtained and the loss between sections is only 100 μ The cut sections are then published on a very fine waterproof Silicon carbide paper no 400 grit and mounted for microscopic and other studies (Figure 2)

## DISCUSSION

The above method has been used with great success to study the growth of bones in rats using the tetracycline marking technique (*Raman* 1965) The apparatus does not entail much expense or upkeep and the results compare favourably with other methods that are used As many

as 20 sections can be made in one hour and the technique is especially suitable for rodent bones which are usually very brittle


## SUMMARY

A rapid and cheap bone sectioning technique capable of producing thin serial undecalcified sections 30–50 µ thick is described The method has been found ideal for making sections of rodent bones

## RESUME

Une technique rapide et bon marche de section des os capable de produire des series de minces coupes de 30 a 50 µ d epaisseur d os decalcifies est decrite Cette methode a ete trouvee ideale pour faire des coupes d os ronges

## ZUSAMMENFASSUNG

Eine rasche und billige Knochenschnittecknik die es ermoglicht dunne 30–50 µ dicke unentkalkte Serienschnitte zu erhalten wird beschrieben Die Methode wurde als ideal zur Herstellung von Schnitten von Nagetierknochen befunden


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From the Department of Orthopaedics (Head Professor Sten Friberg)
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# RESECTION OF VERTEBRAL TRANSVERSE PROCESSES IN IDIOPATHIC SCOLIOSIS

*By*

Olov Lindahl

Received 7 II 66

At least two mechanisms for the deformity in idiopathic scoliosis are conceivable namely skew growth due to genetic or some other disturbance of normal growth and secondly the action of *mechanical forces* by which the various vertebrae are gradually deformed during the time they are developing The former theory of a primary disturbance of growth seems to be the less plausible since it implies that the growth disturbance varies specifically for each vertebra and that it acts in opposite directions above and below the middle of the primary curve The theory relying on the action of external forces seems to be more acceptable as the skeleton is known to be easily deformed during growth if it is subjected to abnormal external forces that interfere with natural development

An analysis of the location of possible forces that from a purely mechanical point of view can produce the various deformities typical of idiopathic scoliosis has been performed by *Lindahl & Raeder* (4) It was concluded that in order to produce a combination of bending and rotation the hypothetical forces would have to be situated in a quadrant posterior and lateral to the involved vertebral bodies (XOY in Figure 1) *Within this quadrant lie the transverse processes* the posterior parts of the ribs and some of the long muscles A restriction of the vertical growth of some or all of these structures on one side might account for the scoliosis

In order to test this hypothesis an attempt has been made to divide some of these structures namely the ligaments and muscles that are attached to the transverse processes

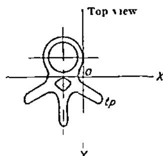



*Figure 1 Model of the spinal column*

## MATERIAL

The operation was performed on 13 cases of idiopathic scoliosis The age and sex distribution the direction on the convexity and the angle of scoliosis are given in Table 1

*Table 1 Age sex and clinical data of the patients undergoing operation*

| Case | Age | Concave side | Scoliosis angle | Resected transverse processes |
|---|---|---|---|---|
| 1 | 14 | left | 114 | Th 6–10 |
| 2 | 12 | left | 117 | Th 6–11 |
| 3 | 10 | left | 114 | Th 6–12 |
| 4 | 14 | left | 69 | Th 7–12 |
| 5 | 15 | right | 65 | Th 10–L1 |
| 6 | 10 | left | 80 | Th 11–L3 |
| 7 | 17 | left | 26 | Th 11–L2 |
| 8 | 12 | left | 50 | Th 5–L1 |
| 9 | 16 | right | 43 | Th 12–L4 |
| 10 | 12 | left | 53 | Th 8–12 |
| 11 | 11 | left | 46 | Th 6–12 |
| 12 | 11 | left | 61 | Th 6–12 |
| 13 | 13 | left | 40 | Th 5–11 |

*Operation Technique*

Under general anaesthesia a 10 15 cm long incision was made 3 5 cm on the concave side of and parallel to the curve formed by the spinous processes The long dorsal muscles were divided in the fibre direction so that the transverse processes were easily accessible These were resected to a length of 1 2 cm and as much as possible of the ligamentous and muscular attachments was removed at the same time The bleeding was usually negligible and after the resection the wound was closed

*After Treatment*

The patients were able to get up the day after the operation and were usually home in 1–2 weeks. They were instructed to exercise the back muscles for a short period and to bend the back so that the concave side was stretched. No great emphasis was placed on this after treatment. No corset was worn.

The follow up period was 6–15 months with a mean of 10 months.

## METHODS OF EVALUATION

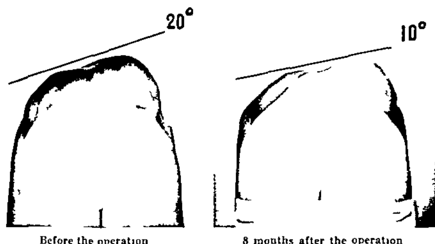
As has been pointed out by Cobb (1) among others it is extremely difficult in the individual case to know whether at a certain time the scoliosis will be stationary or progressive and how rapid any progress will be. It is therefore difficult to decide whether a particular form of treatment has affected the natural course of the scoliosis because after the operation this will not be known. However any reduction in the scoliosis curve obtained without resorting to stretching or any active corrective treatment would be fairly reliable evidence that the treatment given has been effective since no spontaneous regression seems to have been observed by other workers. If regression is not obtained the only entirely satisfactory method for resolving this problem is to perform the operation on a randomly selected half of a large series the other half remaining untreated. No such study seems to have been reported and it would be difficult to realise in practice.

In addition to signs of regression as a criterion of improvement the author has also calculated the mean rates at which the scoliosis angle increased before and after the operation. The monthly increase in the angle was determined for approxi

*Table 2. Pre- and postoperative increase in the scoliosis angle and subjective and objective improvement*

| Case | Before operation: Scoliosis angle | Before operation: Increase in angle degr./mo | Change + – | Post op increase in angle degr./mo | Improvement: Subj | Improvement: Object |
|---|---|---|---|---|---|---|
| 1 | 114 | 0 7 | – | 0 6 | – | – |
| 2 | 117 | 1 6 | – | 0 2 | – | + |
| 3 | 114 | 0 6 | – | 0 5 | – | – |
| 4 | 69 | 0 5 | + | 2 2 | + | – |
| 5 | 65 | 1 6 | – | 0 | + | + |
| 6 | 80 | 0 | + | 0 8 | + | – |
| 7 | 26 | 0 04 | + | 0 9 | + | – |
| 8 | 50 | 1 5 | – | 0 7 | – | +§ |
| 9 | 43 | 1 0 | – | 0 2 | + | – |
| 10 | 53 | 3 0 | – | 1 4 | + | +§ |
| 11 | 46 | 0 4 | + | 0 8 | + | – |
| 12 | 61 | 0 5 | + | 1 2 | + | – |
| 13 | 40 | not known | | 0 7 | + | – |

Evidence of dressmaker § Photograph




Before the operation 8 months after the operation

*Figure 2 The back in forward bending*

mately the same time pre operatively as the patient was followed after the operation and the two figures were compared The angle was determined by *Fergusson's* method (2) An error is incurred in this method—as in others—through the difficulty of obtaining a pure frontal view at the examination and of defining the frontal plane in these patients so as to obtain the same projection in several different examinations Small discrepancies in rotation at different examinations can have a great effect on the scoliosis angle If the rotation of the spine is affected by the operation it will be still more difficult to determine the angle

## RESULTS

In 9 of the 13 cases the patient stated—several times quite spontaneously—that the rotation of the thorax had regressed and that the back felt easier (Table 2) In 2 of these cases the reduction of the rotation was confirmed by the dressmaker who had had to alter the patient's clothes and in 2 other cases by photographs of the back on which the rotation could be estimated (Figure 2) In no case was it possible to detect any reduction in the scoliosis angle on radiographs In 8 of the cases there was a reduction in the mean rate of increase in the angle after the operation in 4 there was an increase and in one no value could be obtained before the operation

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# JUVENILE LUMBAR DISC HERNIATIONS

*By*

ARNE RUGTVEIT

Received 28 V 66

*Intervertebral* disc herniation in children is of interest from an aetiological point of view and also because the clinical picture differs to some degree from that seen in adults

Judging from the reports of operated cases lumbar disc herniation in childhood is extremely rare After *Wahren* (9) described one operated case of disc herniation in a 12 years old child in 1946 several single cases have been reported Of greater significance are four publications (2 5 7 10) which included more patients The largest series is from the Mayo Clinic with five cases below the age of 16 years out of 6 500 operated for herniated lumbar disc

In the Department of Neurosurgery *Rikshospitalet Oslo* during the ten year period from 1956 to 1965 840 patients were operated upon for lumbar disc herniation Seven of these patients were between 11 and 17 years of age

## REVIEW OF CASES

Of seven patients four were boys the rest girls Table 1 describes the ages at the onset of clinical symptoms In one boy these began at the age of seven documented not only by the parent s information but also by motion picture films taken at that time which clearly demonstrates his stiff back Interestingly the father and two cousins had been operated for herniated lumbar discs The remaining material discloses one other instance in which there was a previous disc surgery in the family history

Trauma was implicated as symptom causative in two cases both by the patient and the parents One fell while running and experienced acute low back pain of 2 3 days duration which then subsided until sudden sciatica occurred three months later The other child sustained low back trauma from a fall on the buttocks and similarly had pain lasting only a few days with acute sciatica three months later

There were striking similarities in the child s complaints the parent information and the objective findings in our cases All patients noticed the following Walking

*Table 1*

| | Sex | Age at the onset of sciatica | Age at the time of operation | Duration of symptom at the time of operation | Observation time after surgery |
|---|---|---|---|---|---|
| Case 1 | ♂ | 11 years 3 months | 11 years 9 months | 6 months | 6 years |
| Case 2 | ♀ | 14 years 5 months | 15 years | 7 months | [illegible] years 7 months |
| Case 3 | ♀ | 14 years 5 months | 17 years | 2 years 7 months | 6 months |
| Case 4 | ♂ | 7 years | 13 years 6 months | 6 years 6 months | 2 years |
| Case 5 | ♀ | 15 years 7 months | 16 years 2 months | 7 months | 3 years 2 months |
| Case 6 | ♂ | 16 years 3 months | 16 years 7 months | 4 months | 4 years 5 months |
| Case 7 | ♂ | 13 years 9 months | 14 years 6 months | 9 months | 8 years 5 months |



*Figure 1 A boy with lumbar disc herniation (Case no 4) demonstrates his inability to bend forwards*

*difficulties the scoliotic posture and the child s inability to bend forward* All of the seven children described low backache and sciati pain difficulty in placing on foot ahead of the other and aggravation of the complaints in the sitting position and by coughing and sneezing Each child was able to find relief from his pain by assuming a certain recumbent position Further they could control the pain by avoiding physical exertion and by using particular movement patterns during gait This condition had necessitated refraining from participation in sports

Clinical examination revealed essentially the same sign complex in all patients

1) Spastic guarding scoliosis of the lumbar spine with the convexity toward the affected side

2) Straightening of the lumbar lordosis or slight kyphosis

3) *Extreme restriction of the range of motion in the lumber spine (Figure 1)*

4) Lasegue s test was positive with minimal elevation of the legs None required more than 30 degrees elevation ipsilaterally while the crossed Laseque s test wa positive between 45 and 75 degrees

5) Radicular pain could be produced by palpation in the paravertebral muscula ture corresponding to the affected nerve root

6) Characteristic gait due to the necessity of avoiding flexion of the hip on the affected side and movement in the lumbar spine Two of the patients with a pro lapsed fourth lumbar disc demonstrated a slight reduction of power in the xtensor hallucis longus and a weakened Achilles reflex on the affected side Redu ed sen sibility could not be verified

*Roentgenograms* of the lumbar spine in two planes confirmed the clini al find ings of altered lumbar column axis In three cases the affected disc was r duced in height and in two bone reaction in the adjacent vertebral bodies was noticed (Table 2) Congenital anomalies were demonstrated in three cases among which were two patients with six lumbar vertebrae and one with an asymmetric il sacrali sation of the fifth lumbar vertebra

Preoperative *Abrodilmyelography* (water soluble medium) was perform d in all instances This was negative in three cases although one of these had an earlier myelogram (five months previously) which suggested a prolapse (Tabl 2) In one

Table 2

| | X-ray examination of the spine in 2 planes | Air myelography | Discography | Operative findings |
|---|---|---|---|---|
| Case 1 | 6 lumbar vertebrae<br>Left convex lumbar scoliosis<br>Straightened lumbar scoliosis | Negative findings | Not performed | Extrusion of material from $L_6$ disc left side |
| Case 2 | Slight reduction in height of $L_5$ disc<br>Left convex lumbar scoliosis<br>Straightened lumbar scoliosis | Possible herniation of $L_5$ disc | Not performed | Extrusion of material from $L_5$ disc left side |
| Case 3 | Slight reduction in the height of $L_3$ and $L_4$ disc and slight bone reaction from the adjacent vertebrae<br>Right convex lumbar scoliosis<br>Straightened lumbar lordosis | Possible herniation of $L_4$ disc. Five months later preoperatively: Negative findings | Not performed | Extrusion of material from $L_4$ disc right side |
| Case 4 | 6 lumbar vertebrae<br>Spina bifida $L_6$<br>Right convex lumbar scoliosis<br>Straightened lumbar lordosis | Negative findings | Protruding contrast from $L_4$ disc. Sign of degeneration in $L_5$ and $L_6$ disc | Extrusion of material from $L_4$ and $L_5$ disc right side |
| Case 5 | Slight bone reaction in vertebrae adjacent the $L_4$ disc<br>Right convex lumbar scoliosis<br>Straightened lumbar lordosis | Herniation of $L_4$ disc | Not performed | Extrusion of material from $L_4$ disc right side |
| Case 6 | Slight reduction in height of $L_4$ disc<br>Right convex lumbar scoliosis<br>Nearly straightened lumbar scoliosis | Probably herniation of $L_4$ disc | Not performed | Extrusion of material from $L_4$ disc right side |
| Case 7 | Asymmetrical sacralisation of $L_5$ vertebra<br>Left convex scoliosis<br>Straightened lumbar scoliosis | Herniation of $L_4$ disc | Not performed | Extrusion of material from $L_4$ disc left side |

of the patients with a negative myelogram a subsequent discography revealed protruding contrast from the suspected disc as well as degenerative changes in two other discs

The duration of symptoms before surgical intervention varied from four months to six years and a half All patients had received conservative treatment before surgery including physiotherapy and bedrest Bedrest provided temporary symptomatic improvement in every patient Postural realignment was attempted early during the course of symptoms in some of the patients but was wholly ineffective

*Surgical intervention* was justified on the basis of the duration and intensity of symptoms and the failure of conservative therapy Myelography was particularly important in establishing the level of disc involvement because there were only a few other objective clinical findings which helped in this respect In three patients the myelogram was negative before surgery but in these discography provided valuable information

The operative method employed was a subperiosteal loosening of the paravertebral musculature from the vertebral arch on the affected side followed by arcotomy The interarticular joint was not resected One herniated disc was found in six patients and one patient had two herniated discs The fourth lumbar disc was involved in five patients the fifth lumbar disc in two patients and the sixth lumbar disc in one patient (Table 2) Operative findings in these children did not differ from those normally seen in adults with similar lesions The annulus fibrosus had ruptured and a sequestration which could be extracted by forceps was found in each case The nucleus pulposus of the affected disc and all loose tissue was removed as completely as possible Microscopic examinations of this tissue revealed a cartilagenous structure with degenerative changes

The postoperative course was uncomplicated in all the patients and they later received physical therapy which emphasized strengthening of the back muscles Ambulation was started on the second postoperative day with gradual progression By the time of dismissal 10-13 days after surgery all the patients were improved in condition

During the early months of 1966 six of the seven patients were re investigated by the author both clinically and with x rays The other patient returned a questionnaire Observation time since surgery had varied from six months to eight and a half years (Table 1) In none had there been recurrence of low back pain or sciatica since the time of the surgery Two patients reported some back stiffness and one of these unlike the other six had taken some precautions in his physical activity The six patients investigated clinically had a normal gait were without evidence of muscular atrophy and had no sensory motor deficit Two children still had the scoliosis that was present preoperatively The later two patients had also a restriction of lumbar motion especially for ventral flexion

A-P and lateral x rays of the spinal column were repeated during the follow up studies in six patients The degree of scoliosis was unchanged in one and in another it had increased (Figure 2) No reason could be found in either of these two patients to attribute the scoliosis to a static cause The three patients in whom x rays showed a reduction of disc height before surgery demonstrated the same finding as control but there was no reduction in any other disc There was no case in the bone reaction seen previously



*Figure 9. AP x rays of lumbar column (Case no 4). From left: 3 years prior to, just before and 2 years after disc surgery. The increasing lumbar scoliosis will be evident.*

## DISCUSSION

It is generally accepted that the progressive alterations which occur in the disc with advancing age makes it less resistent to mechanical strain and therefore more disposed to herniation. According to *Inman & Saunders* (8) these changes may begin in the third decade of life or even earlier if the disc has been weakened as a result of trauma or congenital defects. However, it is an open question whether the degenerative changes are an absolute cause of disc herniation. *Hyndman* (4) is of the opinion that a single trauma resulting in prolapse of a previously normal disc is unlikely, and loading experiments of the lumbar spine have established the fact that the intervertebral disc is not the weakest part (1, 3, 6). Therefore disc herniations in children raise interesting problems.

Information concerning back trauma followed by low back pain is found in a high percentage of reported cases of disc herniation in children (2 10) On the other hand we have discovered only two published cases in which sciatica developed as the first symptom after trauma (9 10) Our material includes two patients who had only transient low back pain after trauma but who three months later presented a picture of sciatica

Neither the operative findings nor the histological examinations of herniated intervertebral discs in children gave any significant information which allows us to presume that the pathogenesis of this disorder is different from that in aduls In this we are in agreement with most authors Key (5) however reported four cases of operated disc in children in whom no rupture of the annulus fibrosus was found but a dome like bulging of the disc Key also found no sequesters but on incising the dome like bulging a greyish white gelatinous material exuded Microscopic examination of this material revealed normal disc tissue in three cases, while one showed in addition degenerated cartilage It should be noted that in Key s four cases there was no rupture —only a bulging of the disc which probably is an earlier stage of the herniation sequence On the other hand when evaluating the microscopic findings from frankly prolapsed discs one must remember to consider the time interval between herniation and operation during which pathological anatomical changes may have occurred

Congenital abnormalities possibly important in the pathogenesis of disc prolapse in our seven patients were Two who had six lumbar vertebrae and one patient with an asymmetrical sacralization of the fifth lumbar vertebrae

Similar subjective symptoms and objective signs may be present in both children and adults with herniated lumbar disc but it is important to point out some characteristic differences in the clinical pictures Objective findings dominate in children and their complaints are minor In adults the opposite is most common Other authors have had a similar impression (2 7) Straightening of the lumbal lordosis and a guarding scoliosis are typically found in adults but they are even more pronounced in children As a result Lasegue s test is positive at an unusually small angle of elevation and their difficulties in sitting and walking are more prominent Regardless of these marked symptoms neurological examination provided few objective signs of sensory motor deficit in our cases These differences in findings from those in adults may be explained by a greater ability in children to adapt the

spinal column in a manner which allows more protection to the involved nerve root

The results of operative treatment of herniated lumbar disc in children are gratifying both in our cases and in those of others (2 10) Indications for surgical intervention are fundamentally the same for children and adults In spite of the fact that young patients complain little of pain and that the objective sensory motor disturbances are mild the presence of a marked guarding scoliosis and a strongly positive Lasegue s test justify surgery if efforts at conservative therapy have been unrewarding We would be reluctant to allow a child with a guarding scoliosis to go with this for months or years Our two patients who had scoliosis for the longest period of time before operation still had scoliosis at the time of the follow up investigation and in one it had even increased (Figure 2) The other patients all with complaints of less than nine months duration demonstrated no persistent scoliosis

SUMMARY

Seven patients from 11 to 17 years of age operated upon for lumbar disch herniation were followed up from ½ to 8½ years after operation

Some differences in the clinical picture between children and adults are pointed out Neither the operative findings nor the histological examination of material from the herniated discs permitted the conclusion that the pathogenesis of his disorder is different from that in adults The result of the operative treatment was gratifying In the authors opinion the indication for surgical intervention is fundamentally the same in children as in adults except that in growing individuals we have to pay special attention to the scoliosis

ACKNOWLEDGEMENT

The roentgenological investigations were carried out by the neuroradiologist docent *A Engeset* MD and the pathological examinations by the neuropathologist *Aagot Christie Løken* MD

RESUME

Sept malades agés de 11 a 17 ans opérés pour hernie discale lombaire ont été réexaminés ½ a 8½ ans apres l operation

Quelques différences dans le tableau clinique chez les enfants et les adultes sont relevees Ni les trouvailles opératoires ni les disques herniés permettent cependant de tirer la conclusion que la pathogenèse de

ce dérangement est différente de celle chez les adultes. Le résultat du traitement opératoire a eté satisfaisant. De l'avis de l'auteur, l'indication d'une intervention chirurgicale es fondamentalement la meme chez les enfants que chez les adultes, abstraction du fait que chez l'individu en periode de croissance il faut apporter une attention toute particulière a la scoliose.

## ZUSAMMENFASSUNG

*Sieben Patienten im Alter von 11 bis 17 Jahren, die wegen Lendenzwischenwirbelscheibenhernien operiert worden waren, wurden ½ bis 8½ Jahren nach der Operation nachuntersucht.*

Einige Unterschiede in dem klinischen Bilde zwischen Kindern und Erwachsenen werden hervorgehoben. Weder der operative Befund noch die vorgefallenen Scheibe gestattete die Schlussfolgerung, dass diese Erkrankung von der der Erwachsenen verschieden ist. Das Ergebnis der operativen Behandlung war befriedigend. Der Verfasser ist der Meinung, dass die Anzeige fur den chirurgischen Eingriff wesentlich die gleiche bei Kindern wie bei Erwachsenen ist, abgesehen davon, dass man am wachsenden Organismus der Skoliose besondere Aufmerksamkeit widmen muss.

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From the Department of Orthopaedic Surgery University of Singapore Singapore

# VERTEBRAL COLUMN AND OS CALCIS FRACTURE PATTERNS IN A CONFINED COMMUNITY (SINGAPORE)

## *Notes on Fracture Incidences as Clinical Evidence of Disturbed Bone Metabolism with Increasing Age*

*By*

P C N WONG

Received 15 V 65

## INTRODUCTION

The present study aims primarily at the establishment of fracture patterns for both the vertebral column and the os calcis in the population of Singapore This has now been possible for the first time

A further object is to prove that the increase in fracture incidence of the vertebral column with age also provides important clinical evidence of disturbed skeletal metabolism which is progressive with aging

Both in Sweden (*Bauer* 1960) and Singapore (*Wong* 1965) evidence of such disturbed metabolism has already been produced with reference to the distal radius and the proximal femur and Bauer has also pointed out that in females this disturbance is manifested in the distal radius some 15–17 years before the proximal femur The present investigation also determines this lag period but the scope has been widened to include three fractures *i e* distal radius proximal femur and the vertebral column and for both sexes of the local population

## MATERIAL AND METHODS

### *Population at Risk*

Singapore is the largest city in Malaysia and is inhabited principally by Chinese (75 per cent) with smaller proportions of Malays (14 per cent) Indians (9 per cent) European and Eurasians (? per cent)

In 196? this mixed Asian population was estimated to be 1 8 million

All the age specific estimates in this study have been based on this projected population (Table 1)

*Table 1 Singapore population 1962*

| Age groups | 10–19 | 20–29 | 30–39 | 40–49 | 50–59 | 60–69 | 70+ |
|---|---|---|---|---|---|---|---|
| ♂ | 181 6 | 131 4 | 108 9 | 86 3 | 61 6 | 26 4 | 6 9 |
| ♀ | 170 2 | 1?3 5 | 91 1 | 67 5 | 49 1 | 26 1 | 11 5 |

## MATERIAL

The material consists of all os calcis vertebral fractures and dislocations diagnosed in the whole State of Singapore over the complete two year period 196?–1963 Neither sacral old or pathological fractures were considered There are 171 fractures of the os calcis in 149 patients 22 of whom (15 per cent) sustained bilateral fractures in the one episode Fractures and fracture dislocations of the spine totalled 3?8 These were diagnosed in 255 patients of whom 48 or 18 per cent represented multiple fractures

## RESULTS

### *Fractures and Fracture—Dislocations of the Spine*

#### *Classification*

These injuries are classified in Tables 2 and 3

#### *Sex Distribution*

Of the 255 patients who presented these injuries 189 were males and 66 were females giving a male to female ratio of 3 1

In the Singapore population age 10 and above 603 000 are males and 539 000 are females—a ratio of 11 to 10 There is thus a true male predominance in the sex distribution of these fractures

*Table ?*

| | ♂ | ♀ |
|---|---|---|
| Fracture dislocations | 9 | 0 |
| Compression fractures of the vertebral bodie | 20[illegible] | 81 |
| Fractures of the transverse processes | 2[illegible] | 3 |
| Chip fractures of vertebral bodies | 2 | 1 |
| Fractures of lamina | 3 | 0 |
| Pedical fractures | 1 | 0 |

*Table 3 Fractures of the vertebral column*

| Age groups | | 10–19 | 20–29 | 30–39 | 40–49 | 50–59 | 60–69 | >70 |
|---|---|---|---|---|---|---|---|---|
| No of patients | ♂ | 22 | 45 | 38 | 23 | 39 | 16 | 6 |
| | ♀ | 7 | 4 | 7 | 3 | 17 | 15 | 13 |
| Ratio of moderate | ♂ | 2/20 | 17/66 | | 25/37 | | 17/5 | |
| to severe trauma | ♀ | 4/3 | 2/9 | | 16/4 | | 23/5 | |

## *Age Specific Incidences*

These are calculated from the population figures (Table 1) as the annual incidence of patients and not the number of fractures per 10 000 males or females in each 10 year age group

In both sexes there is a tendency for incidences to rise with age with those of the males exceeding the females in all age groups except the elderly (Figures 1 and 2)

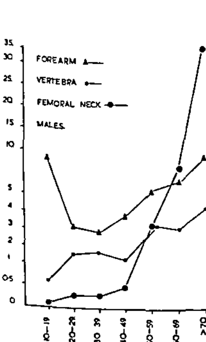



*Figure 1*

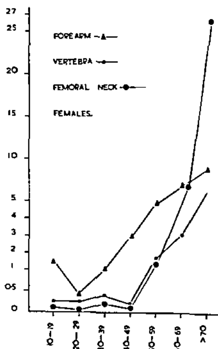



*Figure 2*

### Level of Fracture

The most vulnerable part of the spine is between T10—L inclusive 218 fractures or 66 4 per cent L1 is the most frequently involved vertebra 83 fractures or 25 3 per cent

In the present series 72 of the fractures occurred in people 60 years and above Again the most common site was between T11 and L 41 fractures or 57 per cent and the vertebra most often involved was also L1 17 fractures or 24 per cent which accords well with the figures of 26 per cent quoted by *Key & Conwell* (1961) and 24 per cent by *Rowe & Sorbie* (1962)

### Associated Os Calcis Fractures

Four of the males in the 10-19 group had accompanying fractures of the os calcis 9 in the 20-29 group and 1 each in the 30-39 and 40 49 groups *i e* 8 per cent Only one of the females sustained vertebral and os calcis fractures in the one episode

### Relationship to Trauma (Table 3)

The two degrees of trauma as defined by *Bauer et al* (1962) have also been the ones adopted in this study viz direct high energy trauma and indirect low energy trauma

In males although fractures which are due to severe trauma prevailed at all ages except in the elderly the proportions of such fractures decrease with age In females on the other hand severe trauma fractures prevail only in young adults the proportions of fractures due to moderate trauma increase from young adults through middle age to a maximum in the elderly

### Vertebral Fractures and Electro Convulsive Therapy

Five of the patients (4 males 1 female) sustained their fractures during the course of electro convulsive therapy *i e* approximately 2 per cent and all were located between T and T

### Incidence of Vertebral Injuries with Neurologic Complications

There were 9 fracture dislocations in the series all diagnosed in males and none above the age of 55 Only 1 escaped neurologic complications There were 3 deaths all tetraplegics 3 were paraple

gies one a hemisection of the cord and there was one with root involvement. Neurologic complications among the males in the present series was therefore 4.2 per cent.

### *Incidence of Paralytic Ileus*

In the Rowe and Sorbie series (1963) paralytic ileus developed in 15 per cent and was most commonly associated with fractures involving $T_{12}$—$L_1$ and therefore would appear to support the generally held view *that the underlying factor is a retroperitoneal haematoma which either* by the bulk of the latter or by direct irritation disturbs the coeliac plexus.

No less than 120 or 47 per cent of the patients of this series sustained fractures involving $T_{12}$—$L_1$ only one was complicated by paralytic ileus. This would appear to contradict the coeliac plexus irritation theory.

Two females and 5 males presented signs with micking an acute abdomen (*i.e.* abdominal tenderness guarding and rigidity). This is probably due to blood or haematoma from the fracture site irritating the parietal peritoneum which is known to be segmentally supplied by intercostal and lumbar nerves (*Last* 1954).

### *Fractures of the Os Calcis* (Table 4, Figure 3)

In this series 136 males presented with 157 fractures and only 13 females with 14 fractures. The male to female ration was 11 to 1.

Bilateral fractures were diagnosed in 21 of the males *i.e.* 15.4 per cent and in 1 of the females *i.e.* 8 per cent.

Os calcis and vertebral fractures sustained in the one episode occurred in 15 of the males (11 per cent) and one of the females (8 per cent).

*Table 4. Fractures of the os calcis*

| Age groups | | 0–19 | 20–29 | 30–39 | 40–49 | 50–59 | 60–69 | 70 |
|---|---|---|---|---|---|---|---|---|
| No. of fractures | ♂ | 18 | 37 | 33 | 32 | 28 | 9 | 0 |
| | ♀ | 1 | 6 | 1 | 4 | 1 | 1 | 0 |
| Ratio of moderate to severe trauma | ♂ ♀ | 1/17 | 7/30 | 11/2 | 19/13 | 18/10 | 8/1 | 0 |

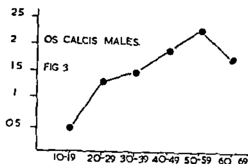



*Figure 3*

### *Age Specific Incidences*

In males incidences increased with age attaining a maximal in the 50–59 group whence it declined a little No calculation was made for the females

### *Relationship to Trauma*

Severe trauma predominated till the end of the third decade moderate trauma was more important thereafter *viz* the proportion of fractures due to moderate trauma increased with age

### *Fracture Incidence as Clinical Evidence of Disturbed Bone Metabolism with Increasing Age*

Incidence of fractures of both the femoral neck and distal forearm of both sexes in the Singapore population have already been shown to rise with the increase in age (*Wong* 1965) Although the rises are less dramatic than those of European communities (*Stewart* 1955 *Bauer* 1960 *Buhr & Cooke* 1959 *Alffram & Bauer* 1962 *Allffram* 1964) they can however still be interpreted as indicating an increasing fragility of these parts of the skeleton with age (Figures 1 and 2)

The increasing age specific incidences together with the increase in the proportions of vertebral fractures due to moderate trauma with age in both sexes in the local population would similarly indicate that the vertebral column among them becomes also increasingly fragile as age progresses

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In the present discussion the age specific incidences of both femoral neck and distal forearm fractures have been recalculated considering only those fractures which were diagnosed over the period 1962–63 and using the 1967 population figures

Incidences of femoral neck and vertebral fractures together rise noticeably at the end of the fourth decade This is more convincing in females than males

Distal forearm fracture incidences however in females rise at the end of the second decade whilst in the males this occurs some 10 years later The lag period between the rise of fractures of the distal radius and ulna and that of the femoral neck and vertebral column is therefore some 20 years in females and 10 years in males (Figures 1 and 2)

The explanation for the increased risk of fractures of the proximal femur distal forearm and vertebral column among those progressing in age can certainly in part be attributed to their accident proneness (*Boucher* 1959 *Buhr & Cooke* 1959) but primarily the reason is a progressive change in the quality of bone This opinion was offered as long ago as 1824 by Astley Cooper and it has recently been revived by *Buhr & Cooke* 1959, *Bauer* 1960 *Alffram & Bauer* 1962 and *Alffram* 1964 Recent work in Singapore (*Wong* 1964 1965) further confirms this

The nature of this change however is not precisely known It may be an osteoporosis or as suggested by *Alffram & Bauer* (1962) it may be a disease with a broad spectrum of penetration not necessarily to be identified with osteoporosis Further work in fracture epidemiology may help in elucidating this

Whatever the mechanisms responsible for the increasing fragility from fracture incidences deduced for Swedish and Asian communities (*Bauer* 1960 *Wong* 1964 1965) it would appear that different bones differ in their response to such mechanisms The distal forearm in both Swedish and local females responds early some 15 to 20 years before the proximal femur

The present investigation shows that the distal forearm in the local males also responds early but at a decade later than the females and that in both sexes the proximal femur and the vertebral column respond at the same time

## SUMMARY AND CONCLUSIONS

In an Asian population of 1 8 million people fracture patterns for the vertebral column and os calcis fractures diagnosed over the 2 year period 1962–63 are determined The series consists of 499 fractures

The principal conclusions are

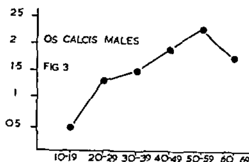



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The increasing age specific incidences together with the increase in the proportions of vertebral fractures due to moderate trauma with age in both sexes in the local population would similarly indicate that the vertebral column among them becomes also increasingly fragile as age progresses

In the present discussion the age specific incidences of both femoral neck and distal forearm fractures have been recalculated considering onl those fractures which were diagnosed over the period 1962–63 and using the 1962 population figures

Zeitraum von 2 Jahren 1962–63 diagnostiziert wurden bestimmt Die Gruppe besteht aus 499 Brüchen

Die wesentlichen Schlussfolgerungen sind

1 Altersspezifische Einflüsse an Wirbelbrüchen nehmen mit dem Alter zu

Die der Männer überwiegen jene der Weiber

2 Der am meisten verletzbare Teil der Wirbelsäule liegt zwischen Th 12–L2

3 Brüche des Calcaneus sind selten bei Frauen

4 Doppelseitige Brüche des Calcaneus sind nicht selten (15 Pro zent der Männer)

5 Brüche des Calcaneus und der Wirbelsäule die im gleichen Unfall erlitten wurden findet man bei 11 pro zent der Männer

6 Welche Mechanismen auch immer verantwortlich sein mögen( die vermehrte Zerbrechlichkeit der Knochen mit zunehmendem Alter) verschiedene Knochen reagieren verschieden gegenüber solchen Mechanismen


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The photographic reproductions of the writer s graphs are by Mr *S H Tow*


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# HYPERALGESIA OF THE LUMBAR NERVE ROOTS IN SCIATICA

By

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Received 7 II 66

Normal peripheral nerves including the spinal nerve roots react to compression by loss of function (1) If the compression occurs rapidly possibly with mechanical deformation and consequent damage to the nerve structure paraesthesia radiating and tingling sensations and more or less pronounced pain will result It is surprising how moderate the pain caused by pressure or a blow on a nerve trunk such as the ulnar or fibular nerve can be Continuous moderate pressure will usually produce only a loss of function with no pain at all

In 1946 *Lindahl* (8) demonstrated that symptoms of impaired function of the lumbar nerve roots such as paraesis areflexia and reduced sensibility occurred in tuberculous spondylitis of the lumbar spine and that these symptoms were unaccompanied by pain In cases of tumours of the spinal canal pain is a common initial symptom but in at least 30 per cent of the cases of benign tumours there is no pain and neurologic symptoms of loss of function mostly paresis usually appear first (2 3 11) It is thus evident that pressure on the spinal nerve roots as in the peripheral nerves can be quite devoid of pain

It is now widely considered that the radiating pain in sciatica it is due to pressure on the nerve roots usually caused by herniated disks This pressure may be described as continuous intermittent or abrasive in type Since pressure on a nerve root does not necessarily involve pain it would seem reasonable to suppose that the sciatica must be due to some other cause besides Evidence for this is found in the great range of intensity of the pain in sciatica even in the absence of herniated disks and likewise in the wide variation in the sensitivity of the nerve roots to pain on pressure and manipulation during operations for sciatica

Since disk herniation was discovered two main explanations of sciatica have been advanced namely a mechanical effect the pain in a nerve root being elicited by pressure on it and secondly inflammation of the nerve In 1947 *Lindahl* (8) proposed that sciatica could occur through a combination of these two factors in some cases inflammatory changes unaccompanied by external pressure would suffice as the explanation while in the case of disk herniation the associated mechanical pressure would of course extend and intensify the pain and evoke symptoms of functional loss but could not be the sole cause of the pain

To study the incidence of pathological changes in the nerve roots *Lindahl & Rexed* in 1951 took biopsy specimens from the posterior spinal nerve roots at operations on cases of sciatica (10) In 7 out of 10 cases pathological usually inflammatory processes were found in the nerve roots some of the patients had disk herniation and others not

In the subsequent discussion on the cause of the pain *Kelly* (4–7) suggested that the theory of mechanical pressure did not fit in with a number of clinical experimental and physiological facts Sharply criticizing Kelly s views *Smyth & Wright* (14) maintained that the pressure of a herniated disk could alone account for sciatica In operations for disk herniation they placed nylon threads round the nerve roots and left them in place for a time after the operation When the pain was relieved after removal of a herniated disk the threads were pulled so that the nerve roots were subjected to pressure the typical pain was again elicited

To examine more closely the sensitivity to pain from the lumbar spinal nerves the author has subjected various lumbar nerve roots to a rapid increase in pressure by an epidural injection of isotonic saline in connection with back operations

## MATERIAL AND METHOD

The experiments were performed on 20 patients operated on for disk herniation and on 4 patients where a posterior fusion was performed for chronic back pains but not sciatica The patients were anaesthetized with a local infiltration anaesthesia adjacent to the spinous process and vertebral arches After exposing these on both sides the epidural space was punctured with 0 ? mm thick needle care being taken to avoid coming into contact with the nerve roots and passing intradurally As a rule the 3 lower lumbar intervertebral spaces on each side were punctured When the needle was in position 10 ml of isotonic saline was injected as fast as possible so that a rapid increase in hydrostatic pressure was obtained around the needle The

patient was told that an injection was about to be given and was asked to say whether it caused any pain and if so where After the pain had ceased—usually after a minute or so—the next space was punctured in the same way In the various experiments the space where the clinical findings or myelography indicated that the herniated disk would be located was injected alternately first and last The clinical syndrome and surgical findings are given in Table 1

*Table 1 Clinical syndrome and findings at operation in the cases of sciatica tested*

| Syndrome | No | Positive findings | Negative findings |
|---|---|---|---|
| $S_1$ | 9 | 7 | 2 |
| L | 7 | 5 | 2 |
| $L_4$ | 1 | 1 | 0 |
| Mixed | 3 | 1 | 2 |
| Total | 20 | 14 | 6 |

## RESULTS

As with few exceptions the patients reaction was remarkably uniform a detailed account of all 24 cases would appear to be superfluous In connection with the injections all the patients with typical root syndrome stated that they felt a pain in the usual area *irrespective of where the injection was made*

The intensity of pain was apparently related to the pre-operative severity of the symptoms When the injection was given at a distance from the root the pain was slightly milder than when it was given just over the root and in some cases the pain on injection at a distance of 3 spaces was very weak In none of the cases was there pain on the sound side where one half of the injections were given

In cases of back pains without sciatica the injection sometimes gave rise to mild diffuse back pains and in two cases to weak radiating pains on the same side as the injection Usually there was no pain

In the 3 cases of atypical sciatic pain implying radiation only in the thigh and lower leg but not the foot or where more than one root appeared to be involved the injection also elicited the characteristic pains but the component reproduced depended on the level of injection In these cases too no pain was felt on the sound side In a number of leading questions 10 of the patients were asked whether there was not now pain in the sound leg and the injection was repeated on the sound side with a needle of larger calibre (1 0 mm) at a faster rate and with

a larger volume (20 ml). In 4 of these cases the patient reported a slight sensation in the sound leg but said that this could hardly be described as pain and could by no means be compared with the pain felt simultaneously in the usual region.

The patients recorded pain sensations that were alike in cases with and without herniated disk.

## DISCUSSION

*It would seem obvious from these experiments that* a normal lumbar nerve root does not react with an appreciable pain sensation to an increase in diffuse hydrostatic pressure produced in its vicinity, an increase in pressure that, as was seen, resembled closely that which may be produced *via* the veins in coughing or blowing the nose. It is also evident that the nerve root or roots that are responsible for the sciatic pain are abnormally sensitive to such pressure. That such a marked variation in the sensitivity of the nerve roots also accompanies mechanical deformation during operative insensitivity of the sound nerve roots has, however, not received much attention in the discussions on the cause of sciatic pain. It is also evident from these experiments that hyperalgesia of the nerve roots occurs in cases of sciatic with and without herniated disk.

It might be asserted that in the cases of negative findings at operation disk herniation may have been present but overlooked, perhaps because it was located lateral to the intervertebral space. While this cannot of course be proved wrong, it must be borne in mind that all 6 such subjects were relieved of pain after the operation and at a follow up examination 6 months later they still had no pain in the legs; there is here no evidence that the pain was due to pressure from a possible residual herniated disk.

It is a familiar experience from all large operation series that the results at a follow up of the "negative" operations are good but not quite as good as after the "positive" operations. *Senning & Sjoquist* (13) reported 50 per cent satisfactory results after negative explorations and *Warris* (15) 71 per cent. This would suggest that the operation for disk herniation can have a therapeutic effect that is not associated with the actual removal of the offending disk, and in fact cannot always be attributed to the relief of pressure in any other way (for instance by laminectomy). This therapeutic effect might well it

seems be due to an influence on the hyperalgesic state of the nerve—a nonspecific irritation therapy

We have now the following facts (1) Pressure on normal nerves does usually not produce pain (2) in sciatica the nerve roots are hypersensitive to pressure to which they react with pain (3) disk herniation or any other source of pressure is not always found in sciatica (4) the surgical treatment for sciatica includes a factor that is unassociated with removal of the offending disk but which still banishes pain in at least 50 per cent of the cases

This evidence suggests the following conclusions (1) Symptoms of loss of function in sciatica are due to compression of one or more nerve roots (2) The mechanical component in sciatica is usually extremely definite (movements loading and function aggravate the pain removal of a herniated disk results in improvement) (3) The pain in sciatica cannot be ascribed solely to mechanical pressure there must be also a pathological alteration of one or more nerve roots which results in hyperalgesia (4) The severity of the sciatic pain is related mainly to the severity of the hyperalgesia Most cases of sciatica are mild and then a herniated disk is neither sought nor found (5) In sciatica the nerve root environment can be anatomically normal but mechanical compression of the nerve roots aggravates the pain and symptoms of functional loss may then be elicited (6) In hyperalgesia the normal physiological contact with a normal anatomic environment can suffice to account for aggravation of the pain by mechanical factors

This explanation of sciatic pain is not of course proven in every respect but it would seem to be more consistent with our present knowledge of sciatict than the theory relying on mechanical compression as the sole cause of the pain

*Smyth & Wright*s (14) experiments with nylon threads have not proved that pressure is the sole cause of sciatica Their patients obviously had hyperalgesic nerve roots the traction on which elicited pain Normal nerve roots would definitely not have reacted in the same way What then is the cause of the "hypothetical hyperalgesia and why is *there reason* to consider it at all when the role of mechanical pressure is still thought to be the major one?

It is of course obvious that our power to eliminate entirely any mechanical effect on the lumbar nerve roots is limited on both theoretical and practical grounds Every orthopaedic department has a not inconsiderable group of patients whose sciatica has not been relieved The discovery of the cause of the hyperalgesia and some way of treating

it would constitute a therapeutic advance that would benefit not only the cases that have resisted our present therapy but also many who have benefited from an operation but who might have been helped more easily without surgery

The cause of the hyperalgesia remains to be found In an earlier paper *Lindahl* (9) showed that the negative pressure in the epidural space normally present is absent in sciatica *Lindahl & Rexed* (10) among others have shown that the nerve roots are the site of pathological changes In some cases the cause may lie with infection A discussion of this possibility and appropriate references are to be found in the paper by *Lindahl & Rexed*

It would seem conceivable also that an inflammatory process in the epidural space can result from outward penetration of disk tissue and perhaps also of metabolic products from the nucleus and annulus Evidence pointing in this direction has been reported by *Olsson* (12) who has shown that such an inflammatory reaction was a more or less regular phenomenon in disk hernia in the dog Such an inflammatory reaction with subsequent hyperalgesia of all the nerves in the region might be a common cause not only of sciatica but also of the much more common lumbago

From a practical standpoint this approach to sciatica is not so far removed from the conventional one and it is perhaps the disk that is in one way or another the most important factor

## SUMMARY

Various theories on the cause of sciatic pain are discussed There are two prevalent views on the cause namely mechanical pressure on the nerve roots and an inflammatory process

With the object of throwing more light on this problem the author has examined the sensitivity of the lumbar nerve roots to hydrostatic pressure in connection with back operations by rapid injection of physiological saline epidurally In cases of sciatica with or without disk herniation one or possibly more nerve root reacted abnormally to pressure and the typical pain was elicited while for the other nerve roots like those in cases without sciatica there was no pain reaction at all

It is suggested that in sciatica there is almost invariably hyperalgesia of the nerve roots and that this is a more or less necessary condition for the sciatic pain It is recognised that a mechanical factor is of prime

importance but this is not inconsistent with the hyperalgesia being an equally important factor in the explanation of the disease


## RESUME

Differentes theories sur la cause des douleurs sciatiques sont discutees Il y a deux opinions qui prevalent a savoir la pression mecanique sur les racines nerveuses et un processus inflammatoire

Dans le but d eclaircir ce probleme l auteur a examine le sensibilite des racines du nerf lombaire a une pression hydraulique en relation avec des operations du dos par une injection rapide d eau salee physiologique epiduralement Dans les cas de sciatique avec ou sans hernie discale une ou peut etre plusieurs racines nerveuses reagissent anormalement a la pression et la douleur typique est provoquee alors que pour d autres racines nerveuses comme celles dans les cas sans sciatique il n y a aucune reaction douloureuse

Il est suggere que dans la sciatique il y a presque invariablement une hyperalgesie des racines et que c est une condition plus ou moins necessaire a la douleur sciatique Il est reconnu qu un facteur mecanique est d une importance primordiale mais cela n est pas contradictoire avec l hyperalgesie comme un facteur d une importance egale dans l explication de cette maladie



## ZUSAMMENFASSUNG

Verschiedene Theorien uber die Ursache von Ischiasschmerzen werden besprochen Es bestehen zwei vorherrschende Ansichten über die Ursache namlich die des mechanischen Druckes auf die Nervenwurzeln und die eines Entzündungsprozesses

Mit der Absicht mehr Klarheit in dieses Problem zu bringen hat der Verfasser die Empfindlichkeit der Lendennervenwurzeln gegenüber hydrostatischem Druck im Zusammenhang mit Rückenoperationen mittels rascher epiduraler Injektionen von physiologischer Kochsalzlosung untersucht In Fallen von Ischias mit oder ohne Diskushernie reagierte *eine oder moglicherweise mehrere* Nervenwurzeln abnormal auf Druck und der typische Schmerz wurde hervorgerufen wahrend die anderen Nervenwurzeln ebenso wie jene in Fallen ohne Ischias keinerlei Schmerzreaktion aufwiesen

Es wird angenommen dass bei der Ischias fast immer eine Hyperalgesie der Nervenwurzeln vorhanden ist und dass dies eine mehr oder weniger notwendige Bedingung für den Ischiasschmerz ist Man er

kennt das der mechanische Faktor äusserst wichtig ist aber das schliesst nich aus dass die Hyperalgesie einen ebenso wichtiger Faktor zur Erklarung der Erkrankung darstellt

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# RESULTS OF RADICAL EVACUATION AND ARTHRODESIS IN SACRO ILIAC TUBERCULOSIS

By

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Received 23 ii 66

Sacro-iliac tuberculosis is a relatively rare disease Even before the introduction of tuberculostatic medication reduced the frequency of bone and joint tuberculosis in general tuberculous sacro-iliitis was seldom encountered Of a total of 3203 patients with lesions of the back treated at the Surgical Clinics I II and III and the Surgical Outpatients Department University of Helsinki during the years 1951 1953 only 0 3 per cent had sacro iliac tuberculosis whilst tuberculous spondylitis for instance was diagnosed in 8 3 per cent (*Bakalim* 1959)

Previously the prognosis of tuberculous sacro iliitis was regarded as poor *Seddon* (1939) reported a mortality of 10 per cent in isolated sacro-iliac tuberculosis 25 per cent in connection with fistulization and 50 per ceent in patients with concomitant tuberculosis in other sites

The disease often begins insidiously with a latency stage of long duration There may be pain in various sites dependong on the location and extension of the lesion Apart from pain in the sacro iliac joints symptoms indicative of other diseases of the lumbar region of the back (*e g* sciatica) or the hip joints may be present

It is a generally accepted view that abscess formation and unilateral localization are indicative of tuberculosis whereas bilateral involvement and complete ankylosis constitute evidence of spondylarthritis ankylopoetica *Brocher* (1949) stated that he had never seen complete ankylosis in tuberculosis of the sacro iliac joint Apart from these two diseases the only pathological conditions of the sacro-iliac joint to be taken into account in differential diagnosis are osteitis condensans ilei and rare primary tumours The roentgenographic appearance of the latter is fairly typical however Increased sclerosis of the bony tissue in

the iliac part of the joint has been described in connection with various conditions in which the function of a lower extremity is impaired (*Solonen* 1957) In these cases the changes of the sacro-iliac joint always develop on the opposite side as a result of the greater strain to which this joint is exposed

Since the discovery of tuberculostatic drugs direct surgical treatment has been attempted in the management of all kinds of bone and joint tuberculosis The aim of eradicating the focus with its mass of granulation tissue and caseous necrosis which constitutes a strain upon the organism is to obtain more rapid healing than what is possible with conservative treatment alone

Operative treatment of bone and joint tuberculosis was first tried at the end of the last century but before the advent of antibiotics the results were unsuccessful Subsequently the predominant principle of conservative treatment utilized the beneficent effects of rest sunshine and fresh air (*Rollier* 1913)

The reports on surgical evacuation of foci adjacent to the sacro iliac joint are few *De la Sierre Cano* (1956) described a series treated by evacuation and subsequent arthrodesis performed by Smith Petersen s method Before the use of chemotherapy among 45 operated cases mortality was 7 per cent whilst the death rate in a conservatively treated series was 15 per cent Thanks to the introduction of tuberculostatic drugs fatal cases has been entirely eliminated however *Horvat* (1956) excised the focus in 3 cases and packed the cavity with bone *Roaf Kirkaldy Willis & Cathro* (1959) too recommended evacuation of the focus These authors performed arthrodesis by packing the cavity with the bone that had been removed on exposition of the sacro-iliac joint It appears that a conservative attitude in regard to therapy is still common Tuberculous sacro iliitis is treated with chemotherapy a plaster bed or an orthopaedic corset until the process has healed After this the patient is usually allowed to be up wearing a corset or arthrodesis is performed (*Adams* 1961) Arthrodesis alone without evacuation must be regarded as a conservative method

## MATERIAL

At the Orthopaedic Hospital of the Invalid Foundation tuberculous sacro iliitis has been treated by operative evacuation and arthrodesis since 1950 The present series is small comprising only 8 cases from the 10 year period 1950–1960 but in view of the low frequency of the disease it seemed futile to postpone a follow up study for the sake of collecting a larger material

The patients' age and occupations appear in Table 1. The erythrocyte sedimentation rate was not elevated in all cases, normal values being recorded in 3. The majority of the patients experienced pain in the affected sacro-iliac joint. In 3 cases an abscess could be palpated over the joint. Tenderness on palpation or percussion was a typical feature. The so-called sacro-iliac tests, by which movement of the joint is indirectly caused, were positive. A fistula was present in 2 cases. In one case the process was bilateral, which is rare, but only one focus was active. Table 1 also shows the occurrence of tuberculous processes in other sites.

*Table 1*

| Case no | Occupation | Age yrs | ESR mm/hr | Other tuberculous foci | Abscess | Fistula |
|---|---|---|---|---|---|---|
| 1 | Farmer's wife | 27 | 6 | Pleurisy, spine | + | + |
| | Housewife | 22 | 10 | Lung | | |
| 3 | Labourer | 36 | 4 | Pleurisy | | |
| 4 | Widow | 62 | 46 | Shoulder joint, spine | | |
| 5 | Farmer | 48 | 34 | — | + | + |
| 6 | Clerk (female) | 29 | 31 | — | | |
| 7 | Seamstress | 46 | 96 | Hip joint | | |
| 8 | Labourer's wife | 21 | 24 | Lung | + | |

In the initial stage of tuberculous sacro-iliitis the process may be so limited as to be hardly recognizable on the roentgenogram. In such cases tomography is a useful aid. As a rule the disease begins as a small focus in the lower part of the joint. As always in tuberculosis of the bone, erosion, unsharp outlines and blurring of the structures signify activity. Prior to operative treatment of the focus its extension must of course be established by tomography.

As soon as the diagnosis was made in the present cases, preoperative treatment was instituted. It consisted of streptomycin, isoniazid and PAS. No plaster bed was used. The operation was performed about six weeks later. It was not regarded as necessary to await normalization of the erythrocyte sedimentation rate. The goal was to evacuate the focus as effectively as possible and thus to accelerate healing by ridding the organism of tuberculous tissue. At the same time arthrodesis was accomplished by bone transplantation. Autogenous bone was used except in one case, in which bone from a bone bank was employed. Streptomycin was administered locally. The joint was incised in the same way as in Smith-Petersen's arthrodesis.

As always when tuberculous foci are evacuated the greatest problem is to find all ramifications of the process. During operation it is not

to inspect all corners of the sacro iliac joint If any tuberculous tissue is left the intervention loses some of its value

In the following the present 8 patients are described in the same order as they were treated

## CASE HISTORIES

*Patient no 1* A farmer s wife aged 27 who had had pleurisy eight years before she was admitted to the Orthopaedic Hospital of the Invalid Foundation She had experienced pain in both hip joints for seven years An inactive tuberculous lesion was present in the fifth lumber vertebra The general condition was not quite satisfactory The erythrocyte sedimentation rate was not elevated Tenderness on percussion was observed all over the lumbar region of the back and in particular over the right sacro iliac joint Half a year previously a fistula had developed in the right gluteal region

*The roentgenogram revealed extensive destruction of the right sacro iliac joint* the upper part of which exhibited a large sharply demarcated focus More distally two small foci were detected The affected area was surrounded by a markedly sclerotic zone

The lesion was evacuated and the fistula was extirpated in September 1950 From the sacro iliac joint a large focus extended into the iliac bone and a smaller focu extended into the sacrum One gram of streptomycin was placed in the cavity after which a muscular flap was introduced No bone transplantation was performed The wound did not heal immediately a fistula developed which did not close until four years later Postoperatively streptomycin PAS and isoniazid were administered

Twelve years later the patient was summoned to a follow up examination She was in good health and able to do all the household work needed on a farm The flexibility of the back was very good in all directions The sacro iliac tests were negative The erythrocyte sedimentation rate was 11 mm/hr The roentgenogram showed a partially ankylotic articular slit with three rather large defects surrounded by a markedly sclerotic zone The process was healed

*Patient no 2* A married woman aged 22 She had devel ped pulmonary tuber culosis one year previously on account of which streptomycin and PAS therapy had been instituted Before admission to the Orthopaedic Hospital of the Invalid Foundation she had experienced increasing pain in the left lower extremity for two months The general condition was good The sacro iliac tests were positive She exhibited slight right sided scoliosis and straightening of the lumbar lordosis The erythrocyte sedimentation rate was 6 mm/hr The roentgenogram showed a tuber culous focus in the left sacro iliac joint The outlines of the joint were indistinct In the articular region three focal rarefactions were discernible the largest one as a defect in the sacrum the size of a hazelnut The outlines of the lower part of the joint were also unsharp The pulmonary process appeared to be active

In Februoray 1951 the focus was evacuated It was the size of the thumb s end and contained caseous necrosis and pus Streptomycin was administered into the wound and the cavity was packed with the bone that had been removed on exposition of the focus Histological examination showed typical tuberculous tissue

The patient died of pulmonary tuberculosis ten years later The postoperative course remained obscure

*Patient no 3* A farmer aged 36 who had had pleurisy eight years ago Some what later a lesion had been observed in the right sacro iliac joint The patient was admitted to the Orthopaedic Hospital of the Invalid Foundation in October 1951 He had experienced pain in the lumbar region of the back which had been stiffer than before The general condition was good The flexibility of the back was some what impaired in the lumbosacral region The erythrocyte sedimentation rate was 4 mm/hr

The roentgenogram showed partial distension of the sacro iliac joint due to bone destruction partial narrowing of the joint and absence of an articular slit The joint was surrounded by sclerotic bony tissue In its lower part a focus was ob served the size of a hazelnut containing a sequestrum like formation

The focus was evacuated in October 1951 Streptom cin was applied locally and the cavity was packed with the bone that had been removed on exposition of the j int

Eleven years later the patient was summoned to follow up examination Flexibili ty of the lumbar region of the back was somewhat impaired The sacro iliac tests were negative There was no local tenderness The erythrocyte sedimentation rate was n rmal The roentgenograms showed an almost ankylotic joint with markedly sclerotic surroundings On tomography no signs of an active process were detected The patient was healthy but did no manual work He lived at a home for disabled veterans

In this case a very old lesion was evacuated Two years after the operation the process had healed

*Patient no 4* A widow aged 6? who had been under hospital are three years ag f r a tuberculous process in the fifth lumbar vertebra Spinal fusion had been perf rmed Three months after she had discharged the right sacro ilia joint be came tender A roentgenogram showed nothing noteworthy At this time she still received antituberculous medication on account of the process in the spine Bed rest was prescribed and the tenderness disappeared Half a year later she was re ad mitted to the Orthopaedic Hospital of the Invalid Foundation The erythrocyte sedimentation rate was 46 mm/hr The roentgenogram showed a very large focus of bone destruction in the right sacro iliac joint In the lower part of the joint a large sl t had developed The outlines were blurred No sclerosis could be detected

In July 1953 the tubercolous focus was evacuated The sacro iliac joint was found to be completely destroyed The lesion extended into the sacrum and into the ileum Furthermore the pelvis exhibited a large abscess which was evacuated Strepto mycin was placed in the wound Owing to the patient s ad anced age no bone trans plantation was made Postoperatively combined streptomycin PAS and isoniazid treatment was given The patient was treated with bed rest for ten months after the operati n

At follow up examination nine years later the patient was healthy The erythro cyte sedimentation rate was 12 mm/hr All sacro-iliac tests were negative Tomo graph showed that the sacro iliac joint was ankylotic and comprised a large defect

surrounded by markedly sclerotic tissue The defect had decreased considerably however since the previous follow up examination

In this case the most remarkable features were the patient s advanced age and the fact that she was under antitubercolous treatment on account of a spinal lesion at the time of onset of the process in the sacro iliac joint

*Patient no 5* A farmer aged 48 who had a tuberculous process in the right sacro iliac joint since 1941 He had twice been operated upon at other hospitals on this account the first time in 1941 when a fistula developed On admission to the Orthopaedic Hospital of the Invalid Foundation the general condition was good A fistula was present in the right sacro-iliac joint and another in the right inguinal fold The former discharged pus Fistulae were also observed in the left sacro iliac joint and in the left gluteal region The erythrocyte sedimentation rate was 31 mm/hr

The roentgenogram revealed a rarefaction in the right sacro iliac joint the size of a finger tip with a sequestrum in the middle The joint surfaces were throughout sclerotic The left sacro iliac joint was in part completely ankylosed and it was also surrounded by markedly sclerotic bony tissue Fistulography was only in part successful

In November 1954 the focus in the right sacro iliac joint was evacuated and fistulectomy was performed The focus was the size of a plum Streptomycin was applied locally and the cavity was packed with bone from a bone bank Postoperatively ordinary streptomycin and PAS therapy was administered and the patient was treated with bed rest for three months Fistulization did not recur

At follow up examination eight years later the patient had been healthy for seven years and had worked on his farm although he had abandoned the heavies work The sacro iliac tests were negative Roentgenograms showed healing of the lesion on both sides Two small defects were visible in the right sacro iliac joint one in the middle and one more distally The surrounding bony tissue was markedly sclerotic The erythrocyte sedimentation rate was 12 mm/hr

*Patient no 6* A female clerk aged 29 who had mostly been healthy During a pregnancy she began to experience low back pain and stiffness of the left leg and she began to limp She was treated for ischiatica at another hospital but the symptoms grew worse and she developed pleurisy The delivery was normal The trouble in the back persisted and in the end she walked with the aid of a walking stick

When the patient was admitted to the Orthopaedic Hospital of the Invalid Foundation a swelling the size of a fist was observed over the left sacro-iliac joint The erythrocyte sedimentation rate was 32 mm/hr

The roentgenogram showed destruction of the left sacro iliac joint The outlines were very unsharp The calcium content of the osseous tissue was normal A tomogram showed destruction of the sacrum and ileum adjacent to the lower part of the joint The contours of these bones were blurred

In September 1958 the focus was evacuated The cavity was packed with spongy bone from the ileum Furthermore the bone plate removed on incision was used Streptomycin was placed in the wound and postoperatively the patient received streptomycin PAS and isoniazid

At follow up examination four years later the patient was healthy She had taken

up office work nine months after the operation The sacro iliac joint was symptom free The sacro iliac tests were negative The erythrocyte sedimentation rate was 4 mm/hr Roentgenographically the joint was entirely ankylosed and sclerotic There were no signs of tuberculous activity These findings were confirmed by tomographs

*Patient no 7* A sempstress aged 46 who had developed tuberculosis of the hip j in at the age of 12 During the years 1950 1953 she had visited the outpatient d partment of the Orthopaedic Hospital of the Invalid Foundation on this account M bility of the hip joint was markedly limited and the extremity of the same side was shorter than the other In 19 9 the patient began to experience pain in the lumbar regi n of the back and in the left hip She was admitted to the Ho pital in December 1959 The sacro iliac tests were all positive The erythrocyte sedimentation rate was 9f mm/hr The roentgenogram showed a large focus of destruction in the l wer part of the sacro iliac joint Antituberculous therapy was instituted and one m nth later in January 1960 the focus was evacuated The whole j int cavity was f und t be destroyed and two branches of the process projected into the sacrum All tissue showing caseous necrosis was removed Streptomycin was locally applied and the large cavity was packed with bone chips Half a year later the erythrocyte sedimentation rate was 9 mm/hr Two years later the joint was still tender and as no fusi n could be detected another operation was performed which revealed a focus situated m re distally It was evacuated and the cavity wa packed with bone fr m a b ne bank. In addition the bone plate rem ved n excision of the f cu was u ed In this case the course was initially unfav urable from the standp int of heal ng The patient required treatment f r four years Later the pr cess healed but at the la t follow up examinati n ankylosis had not developed with certainty The erythroc te sedimentati n rate wa 11 mm/hr

*Patient n 8* A labourer s wife aged 21 who had been treated nine years age at a sanatorium for patients with pulm nary tuberculosis Before admission to th Orth paedic H spital of the Invalid Foundation she had experienced increasing pain f r three m nths in the lumbar region of the back to the left The pain radiated into the left femur The patient had a limp and experienced difficulty in walking Swelling ver the sacro iliac joint was ob erved All sacr iliac test were positive

The roentgenograms reveale l changes in the wh le of the left sacro iliac j int The outlines were indistinct and bone destruction and decalcification were observed In addition an ld rupture of th symphysis and slight o teochondrosis in the th ra al region f the spine were detected The erythr c te sedimentati n rate was 24 mm/hr

In February 1960 the focus was evacuated The cavity was packed with bone ch ps fr m the plate which had been removed n excision of the f cus Streptomycin wa placed in the wound After operation bed re t for three months was prescribed aft r which the patient was gradually all wed to be up At this time a fre h active p lm nary tuberculosis was detected and the patient was treated f r tw months at a sanat rium In spite of this complication the process in the sacro iliac joint h led satisfact rily The patient wore an orthopaedic cor et of cl th for one year aft er the operati n

At follow up examination three years later the patient was healthy She had no subjective symptoms in the back, and she did all her own household work and nursed her children The erythrocyte sedimentation rate was 19 mm/hr The sacro iliac tests were negative Roentgenographically the sacro iliac joint was in part ankylosed In the lower part a defect was still visible The surroundings of the joint were markedly sclerotic No active lesions were revealed by tomography either The pulmonary tuberculosis had also healed

## RESULTS OF TREATMENT

The patients who had been operatively treated were summoned to follow up examinations In the meantime one patient had died of pulmonary tuberculosis At the clinical examination attention was mainly attached to local tenderness signs of abscess and the responses to the sacro iliac tests Furthermore the investigation comprised roentgenography of the sacro iliac joints including special views in oblique projection tomography and roentgenography of the thorax In addition the erythrocyte sedimentation rate was determined and urinary culture on Lowenstein s medium was performed

The period of observation varied between four and twelve years The main results of the following up studies are compiled in Table 2

*Table 2*

| Case no | Time of observation in years | Subjective symptoms | Sacro iliac tests | ESR mm/hr | Roentgenographic findings | Occupation |
|---|---|---|---|---|---|---|
| 1 | 12 | Symptom free | — | 11 | Ankylosis | Farmer s wife |
| 2 | Dead | | | | | |
| 3 | 11 | Symptom free | — | 4 | Ankylosis | Pensioner in home for disabled |
| 4 | 9 | Pain in lumbar back | — | 12 | Ankylosis | Pensioner |
| 5 | 8 | Symptom free | | 19 | Ankylosis | Farmer (not doing heavy work) |
| 6 | 4 | Symptom free | — | 4 | Ankylosis | Clerk (female) |
| 7 | 4 | Symptom free | — | 11 | No activity no ankylosis | Sempstress |
| 8 | 4 | Symptom free | | 19 | Ankylosis | Housewife |

None of the patients exhibited local tenderness over the sacro iliac joints No abscesses and no open fistulae were observed

The sacro iliac tests were negative in all cases

Six of the 7 patients were subjectively symptom free One patient (No 4 in Table 2) experienced low back pain but nothing noteworthy could be detected

The erythrocyte sedimentation rate was elevated in one case (No 8 in Table 2) This finding could not be accounted for

Roentgenographically no signs of activity in the form of blurred structures with diffuse outlines were detected Complete ankylosis such as is seen in spondylarthritis anchylopoetica did not occur The articular slit was partly visible on the roentgenograms ankylotic sections alternating with gaps Irregular markedly sclerotic areas were a typical feature It should be borne in mind that sclerosis is typical of the reparative stage of bone tuberculosis

The roentgenograms of the thorax showed no active lesions

Fresh tuberculous foci had not developed in other sites

Urinary culture on Lowenstein s medium revealed nothing noteworthy

Five patients out of 7 were fit for work Of those unable to work one was pensioned on account of old age and the other lived in a home for disabled veterans The sacro iliac joints of both these patients were symptom free

## DISCUSSION

The purpose of the present follow up study was to analyse the results of radical operation and arthrodesis in the cases of sacro iliac tuberculosis treated by this method at the Orthopaedic Hospital of the Invalid Foundation during the years 1950–1960

Although the series is small a follow up study was considered to be of interest from the standpoint of evaluating the usefulness of operative treatment in the future

The objective of operative evacuation of a tuberculous focus is to rid the organism all at once from the affected mass including necrotic tissue sequestrum and pus This method of treatment has become possible thanks to the discovery of antibiotics

Surgical treatment of the focus must however be preceded by antibiotic medication for about six weeks There is still reason to remember the complications formerly threatening in the form of miliary tuberculosis and meningitis

In connection with operative treatment the following aspects attract

most interest 1) indications 2) the need of arthrodesis 3) the results of treatment 4) mortality

Radical excision with simultaneous transplantation of bone in order to cause ankylosis should be considered in all cases of tuberculous sacro iliitis As compared with other sites the sacro iliac joint is relatively easy of access although with the reservation that it may be difficult to find all ramifications of the process which sometimes extend far into the sacrum and the iliac bone It is essential to establish the extension of the lesion with the aid of tomography prior to operation

The aim should be to bring about arthrodesis This is accelerated by packing the cavity with autogenous spongy bone

Considerable attention should be paid to the post operative treatment Medication should be extended over a period of two years The problems of resistance are probably the same in bone tuberculosis as in other forms of the disease but no detailed analyses of this question have been published An attempt was made to master these difficulties by combined treatment with several preparations

In the present series the results of treatment were good Ankylosis had developed in 6 out of 7 patients (85 7 per cent) All 7 patients were healthy

No deaths occurred in combination with operation Fatalities can certainly be avoided by careful consideration of the indications in each case Thorough pre and postoperative treatment is of fundamental importance

SUMMARY

A series comprising 8 cases of tuberculous sacro iliitis treated by operative evacuation of the focus and arthrodesis is surveyed The operation was performed after six weeks treatment with streptomycin isoniazid and PAS The period of observation varied between four and twelve years Six patients out of 7 were symptom free One patient died of pulmonary tuberculosis In all 7 cases the process had healed Five patients were fit for work Two were pensioned one on account of old age the other on account of a war injury

Radical excision with simultaneous transplantation of bone should be considered in all cases of tuberculous sacro iliitis The sacro-iliac joint is easy of access Accomplishment of arthrodesis is desirable and is accelerated by simultaneous bone transplantation Ankylosis had developed in 6 cases out of 7 No fatalities occurred in connection with

the operation The pre and postoperative treatment is of fundamental importance


RESUME

Une serie comprenant 8 cas de tuberculose sacro iliaque traites par evacuation operatoire du foyer et arthrodese est examinee L operation a ete pratiquee apres un traitement de six semaines par la streptomycine isoniazide et PAS La periode d observation a varie entre quatre et douze ans Six malades sur 7 n ont aucun symptome Un malade est decede de tuberculose pulmonaire Dans tous les 7 cas le processus a ete gueri Cinq malades ont éte capables de travailler deux ont ete a la retraite l un par suite de son age l autre en raison d une blessure de guerre

Une excision radicale avec transplantation simultanee d os doit etre prise en considération dans tous les cas de tuberculose sacro iliaque L articulation sacro-iliaque est facilement accessible L accomplissement de l arthrodese est souhaitable et est accelere par une transplantation osseuse simultanee Une ankylose s est developpee dans 6 cas sur 7 Aucun incident fatal n est intervenu en relation avec l operation Le traitement pre- et post operatoire est d une importance fondamentale



ZUSAMMENFASSUNG

Eine Reihenfolge von 8 Fallen von tuberkuloser Sacro-Ileitis die mittels Ausraumung des Herdes und Arthrodesis operative behandelt wurden wird vorgestellt Die Operation wurde nach einer sechswochigen Vorbehandlung mit Streptomycin Ioniazid und PAS ausgefuhrt Die Beobachtungzeit war zwischen vier bis zwolf Jahren Von 7 Patienten waren 6 symptomfrei Ein Patient war an Lungentuberkulose gestorben Bei allen 7 Patienten war der Prozess abgeheilt Funf Patienten waren arbeitsfahig Zwei Patienten waren pensioniert der eine wegen seines Alters der andere wegen einer Kriegsbeschadigung

Radikale Excision zusammen mit Knochenverpflanzung sollte in allen Fallen von tuberkuloser Sakro Ileitis erwogen werden Das sacroiliakale Gelenk ist leicht sugänglich Erhaltung einer Arthrodese ist wunschenswert und wird mittels gleichzeitiger Knochenverpflanzung beschleunigt In 6 von den 7 Fallen kam es zur knochernen Ankylose Kein Todesfall trat in Verbindung mit der Operation auf Die vor und nachoperative Behandlung ist von grundstatzlicher Bedeutung

operative training programme several times so that he is familiar with *the treatment postoperatively*

Having started the training in this way we consider the operation to be just an episode in the programme of treatment and in fact most *patients see it in that way*

The patients are not operated upon until they feel absolutely confident in the department—and never until all natural functions are under *control (urination and evacuation)*

## INDICATION

for operation is found when the hip flexion contracture is more than 15 degrees

Below *that size of contracture I feel that most younger patients are* able to compensate in their lumbal spine without any significant disturbance of posture or gait

*At the operation we make an elongation of the psoas tendon* In cases when the rectus tendon is found to be short or when severe spasm is present an elongation of the rectus tendon is performed

*In cases where the sartorius muscle is short or the muscle is found* to be spastic it is transferred to the inferior iliac spine

Additionally it should be stated that fasciotomies of the fascias *covering the tensor fasciae latae and the medial gluteal muscles* are performed just below the iliac crest when necessary to complete extension of the hip joint—just as all fascial layers on the front side of *the thigh are divided transversely* when they give any resistance to full extension

## TECHNIQUE

1) The patient is placed on the operation table in supine position with the buttocks on a sand bag Placed in this way all tight structures may be palpated during the operation
2) A towel covering the genitals and the perineum should be *fixed by sutures in* such a way that one has free access to the adductor muscles if tenomyotomies are required
3) Incision begins at the lateral border of the superior iliac spine following the lateral border of the sartorius muscle to the middle of the thigh
4) The sartorius sheath is opened and the sartorius muscle and the lateral cutaneous nerve of the thigh are exposed
5) The sartorius muscle is mobilized as far as *the superior nerve* supply raised on a finger and cut near the attachment
6) The sartorius muscle is retracted to the medial side so that the rectus tendon is visible and can be exposed right up to the insertion

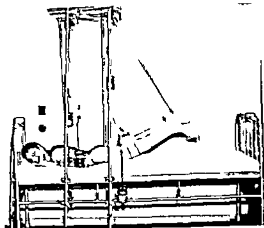


*Figure 1 Patient suspen led—legs in plaster casts balanced with weights*

7) The rectus tendon is cut obliquely
8) The femor l nerve is exposed and the motor branches are isolated
9) Between the motor branch to the rectus femoris and the other branches the circumflex vessels are isolated and the superior branches are ligated and divided Dividing these vessels facilitates access to the distal part of the iliac muscle
10) Now the hip is flexed and abducted the femoral nerve retracted to the medial side and the psoas tendon is visible The lesser trochanter is easily palpated
11) The distal part of the iliac muscle is re ected from the insertion on the psoas tend n and the surrounding femoral bone proximally until 1 + inch from the level of the superior iliac spine Before resection tie or coagulate smaller vessels to the muscle
12) At this time palpation will reveal an tightness of the facial layers which are divided transversely
13) The cleaned psoas tendon is cut obliquely and sutured with a lengthening of 4-6 cm
14) The rectus tendon is sutured with a lengthening of about 3 4 cm
15) The proximal end of the sartorius is sutured to the inferior iliac spine in con nection with the rectus tendon
16) Wound is closed b suturing The longitudinal but not the transverse incisions of the fascial layers should be sutured Catgut in the subcutaneous tissue and nyl n suture in the skin

*After operation* Plaster casts are applied from the groin to the toes with the int nti n of

*Firstly* Treating an eventual flexion contracture of the knee joint

*Secondly* Treating an inward rotation contracture by means of an adjustable tr n er ss bar

*Thirdly* To exclude synkinetic movements in knee and ankle joints in the post operative peri d of training

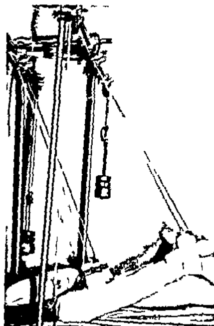


*Figure 2 Patient with a sandbag on the buttocks Details of the suspension arrangement are visible*

*Postoperative Treatment after Elongating of the Psoas Tendon*

1) Treatment starts 1–2 days after operation
2) Legs are in plaster cests from the groin to the toes—the knees are extended and the feet are in neutral position

*Position*

1) Prone twice a day for 2 hours—a sandbag is placed on the buttocks
2) Prone twice a day for 2 hours—with the legs being suspended balanced with weight permitting a gradual increasing of the hip extension
3) The patient is not allowed to sit up in bed

*Exercises*

1) Side-lying position abduction also against resistance
2) Prone position active extension of the hips al against resistance
3) Supine position active outward rotation of the stretched legs also against resistance

*Plaster casts are removed 3 weeks after operation*

*Exercises*

1) Maximum extension of the hips
2) Hip elevation standing on the opposite leg
3) Foot exercises—specially reciprocal dorsi plantar flexion

4) Walking exercises eventually with Canadian crutches
Exercises must continue for 3 months or more
The patient should *sit* as little as possible preferably standing or lying in prone position

## THE MATERIAL

On the 1st of April 1965 our material consisted of 58 patients in whom 111 psoas tendons were elongated

Of these 53 were bilateral and 5 monolateral

28 were females 30 were males

There have been no complications

*Figure 3 shows age in four groups under different diagnoses*

| | Age in years | | | | Number of cases |
|---|---|---|---|---|---|
| | 0–5 | 6–10 | 11–15 | >16 | |
| Diplegia | 1 | 18 | 15 | 4 | 38 |
| Hemiplegia | | 1 | 4 | 2 | 7 |
| Triplegia | | | | 1 | 1 |
| Tetraplegia | 1 | 4 | 6 | 1 | 12 |

*Figure 4 shows the reduction of hip flexion contracture obtained by the combined treatment*

b = flexion contracture *before* operation
a = flexion contracture *after* operation and postoperative treatment

| | | Degrees of hip flexion contracture | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 1–15 | | 16–34 | | 35 | | 0 |
| | | b | a | b | a | b | a | |
| Diplegia | 39 | 1 | 16 | 27 | 0 | 10 | 0 | 22 |
| Hemiplegia | 7 | 1 | 3 | 5 | 0 | 1 | 0 | 4 |
| Triplegia | 1 | | | 1 | | | | 1 |
| Tetraplegia | 2 | 0 | 5 | 9 | 0 | 3 | 0 | 7 |
| | | 2 | 24 | 42 | 0 | 14 | 0 | 34 |

From the figure it will be seen that no patients were left in the two groups with hip flexion contracture of more than 16 degrees

34 patients had no hip flexion contracture

Since then we have performed this operation on some thirty patients who have not been reexamined

24 had a contracture less than 15 degrees

Among these were several with a minimal contracture

*The gait* is improved in all cases subjectively and objectively The patients say that they not get tired so quickly as they did before operation

*The posture* is improved in many cases Before operation 40 patients had a hyperlordosis and after operation only 2 had a persisting hyper lordosis

*Forward tilting* of the body is more common after operation in patients who are mentally defective

## COMMENTS

Earlier methods of treatment of the hip flexion contractures such as teno myotomies or osteotomies followed by plaster casts have given *unsatisfactory results*

The reasons are frequent complications such as decubital ulcers and the lack of active treatment through long periods of time

Closed operations often left tight structures compromising the results (*Cohen 1966*)

If for example by an adductor tenotomy a tenotomy of the psoas tendon is performed the effect on the flexion contracture of the hip may be small as a big part of the iliac muscle may maintain the contracture

For these reasons I consider wide open operations to be necessary in cases with hip flexion contracture (*Mulroy* 1966)

Tendons must be elongated if they are shortened or if their muscles are very spastic

Fascial layers must be divided where they are a hindrance to full extension

*Capsulotomy of the hip joint is not necessary to obtain satisfactory* results

Haemostasis must be complete

Early mobilization and training must be considered as one of the *most important features of the treatment* and absolutely necessary to secure a good result—and because of the altered muscle balance around the hip joint after the operation training and exercises must continue for a very long time

## SUMMARY

The operative treatment of the hip flexion contracture in cerebral palsy patients must be combined with early active exercises and training

The operation of the hip flexion contracture is described and the programme for the postoperative treatment is given in detail

111 elongations of the psoas tendon were performed up to April 1965

The number has steadily increased since then

The primary results are reported

## RESUME

Le traitement operatoire de la contracture de flexion de la hanche chez les malades souffrant de paralysie cerebrale doit etre combine avec des exercices actifs et un entrainement instaures tres rapidement

L'operation de la contracture de flexion de la hanche est decrite et le programme du traitement post operatoire est donne en detail

111 elongations du tendon psoas ont ete pratiquees jusqu en Avril 1965

Depuis leur nombre n a cesse d augmenter

Les resultats primaires sont rapportes

## ZUSAMMENFASSUNG

Die operative Behandlung der Huftbeugekontraktur bei Patienten mit cerebraler Parese muss mit frühzeitigen aktiven Übungen und Training verbunden werden

Die Operation der Huftbeugekontraktur wird beschrieben und das postoperative Behandlungsprogramm wird bis ins einzelne dargelegt

111 Verlangerungen des Psoassehne wurden bis zum April 1965 ausgefuhrt

Ihre Anzahl hat seither stetig zugenommen

Es wird uber die primaren Ergebnisse berichtet


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*circulation of the extremity to be examined with sufficient accuracy for conclusions to be drawn from the results of reconstructive surgery*

In defining the results of reconstructive surgery four phases stand out

1 the initial degree of progression of the arteriosclerosis
2 the method of reconstruction
3 the primary result
4 the secondary result—*i e* the appearance of new symptoms during the period of observation

These four variables together form the factors by which the surgical results of arteriosclerotic treatment should be evaluated

The degree of progression of arteriosclerosis of the extremities is the first variable To ascertain this arteriography is indispensable

*The best indications for operation are those of the first degree in* which the occlusion or narrowing is between the popliteal artery and the lower part of the aorta and the disease is local and segmental being limited proximally and distally to a healthy or nearly healthy artery Physiologically this means that the flow into and out of the segment to be reconstructed is good First degree symptoms also include cases of narrowing in one two or three bifurcations with possibly a thickened intima between them In first degree cases peripheral functional atrophy of the artery resulting from low blood pressure can be observed

Group II—second degree indications—includes cases in which arteriosclerotic changes have produced distal occlusion or narrowing Occlusion in the region of the iliac artery thus involves occlusive disease in the area of the thigh and calf Occlusion in the area of the thigh also involves arteriosclerosis of the calf The part to be reconstructed is still segmental *but there is arteriosclerosis* on the distal side In such cases the initial indications for surgery are not optimal because the occlusion of the calf does not lend itself to reconstruction and the circulation will not be fully restored postoperatively though the primary *results will be better than the initial state*

Group III third degree indications—comprises cases in which the changes are diffuse and dispersed over wide areas No segmental localization can be found Rest pain and gangrene are frequent symptoms Treatment may involve a choice between *reconstruction* and amputation

Methods of surgical reconstruction constitute a second variable. At present three principal methods are being used in varying ways at different hospitals: vein autograft by-pass, endarterectomy, combinations of these two, and plastic prosthetic by-pass in the thigh (*Dale* 1959, *DeBackey et al.* 1964, *Szilagyi et al.* 1964). Endarterectomy and prosthesis are performed in the iliac artery and the lower part of the aorta (*Darling & Linton* 1964, *Hardin* 1964). Combinations and variation of these methods exist. Faschia lata tubes have been used in some hospitals (*Darling & Linton* 1964). Minor differences in technical details increase the variety to some extent. According to the present literature plastic tube by-pass in the thigh is not so effective as the other methods (*DeBackey et al.* 1964, *Szilaggi et al.* 1965).

The primary result—the third variable—depends largely on the first two variables. Circulation can be almost entirely restored to the extremity provided that he occlusion has been eliminated and that there is none in any other part of the extremity (Group I). In Group II the result depends not only upon the part opened up but also on the arteriosclerosis in the lower extremity (calf and foot). The primary result is a partial improvement in the circulation of the extremity. In Group III the primary result may be preservation of the extremity, elimination of rest pain and healing of gangrene (*Linden* 1960). In unsuccessful cases the reconstructed area occludes again and the circulation of the limb may even deteriorate.

The secondary result—the fourth variable—is the final outcome of reconstructive surgery and is correlated to all the other variables. A good sign is preservation of the circulation in the extremities in the same condition as it was as a primary result. The absence of symptoms and the time during which circulation is preserved provide the proof of the importance and utility of the operation performed. Reocclusion can be noted and its cause can be discovered by means of a fresh arteriography.

## MATERIAL AND METHODS

The material comprised 81 cases of arteriosclerosis treated operatively at the Kuopio Central Hospital. All the patients were men except one. Their ages varied from 38 to 68, average 56.4 years. Seventeen displayed signs of cardiosclerosis, four of earlier cardiac infarction, ten of arterial hypertension (under 200 mmHg) and two of diabetes. The operations were performed between 1959–1964.

In the earlier operations the methods employed were the vein by-pass method (VBP) and endarterectomy for short local occlusions in the thigh. Where necessary

VBP was supplemented by proximal endarterectomy (removal of *intima*). In the later cases longer endarterectomy of the thigh was practised and VBP was *used* only in cases where endarterectomy was found to be technically impossible. Endarterectomy was also practised in the region of the iliac artery and *lower a rta*. The method was applied equally to partial occlusions with a cleaning *operation for* the bifurcations. The teflon by-pass method was only used in a few cases.

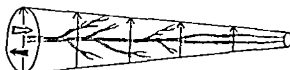
The methods were adapted to the state of progression. These (Groups *I, II and* III) have been described above and represent the extent of the disease and the severity of the symptoms in the extremity. The relation between the methods of operation and the degree of severity can be seen from the actual numbers of *each* shown in the following table.

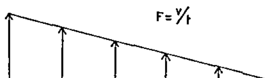
| Degree of severity | VBP | FE | A-I E | TP | |
|---|---|---|---|---|---|
| I | 14 | 12 | 29 | – | 55 |
| II | 6 | 5 | 6 | – | 17 |
| III | 1 | 3 | 2 | 3 | 9 |
| Total | 21 | 20 | 37 | 3 | 81 |

Thus the principal indications of operation (55/81) were local occlusions in the thigh and iliac artery. The interpretations of arteriography were confirmed by the operative findings. This class also includes cases in which mild thickenings of the intima were observed outside the reconstructed part though there was no sclerosing and narrowing disease. Cleaning operations are also included in this class even when the disease appeared at two or three bifurcations. Reconstructive methods were used in 17 out of 81 cases, almost a quarter of the material, representing the second degree of severity. In these cases there was occlusive disease in the peripheral side of the area operated in the thigh or calf. Certain cases with severe symptoms (3rd degree), rest pain, incipient gangrene and occlusive arteriosclerosis over a wide area were treated operatively. These numbered 9 and in three of them teflon prostheses were used.

*Techniques.* In the VBP method a loose prepared long saphenous vein was turned upside down. An anastomosis, an oblique end to side, was made in the artery distally above or below the knee. A proximal anastomosis was made in the upper part of the superficial femoral artery or in the common femoral artery. Where necessary the femoral bifurcation and common femoral artery were cleaned by means of endarterectomy. 50 mg of heparine was injected in a single dose. 5–0 silk was used to close the anastomosis (*Linden* 1960).

Endarterectomy of the femoral artery was performed by the semi-closed method with blunt ring strippers using 2–4 arteriotomic incisions. In the earlier operations the arteriotomy was closed without patches but in the later ones we used vein or teflon patches in the femoral artery. Thickened intima were fixed with stitches in the wall of the artery at the lower part of the endarterectomy. In the iliac part we used 4-0 silk and in the common iliac and aorta double continuous stitching. After the calcification had been removed the artery was found to be strong enough pro-













*Figur 1*

vided the lamina la tica exte na remain d Th re we e n p st perative arteri l ruptures Onl in f w a w re tefl n reinf r ement p tches required Where sp t leaks ppear f u gig *a u ed ucc fully t c agulate the blood Sym* pathect my of th 4th 5th lumbal g nglia wa coml ned with iliac endarterectom e pecially wh n th di ea s a al p riph ral In the e case antic agulation w s c ntinue l y t y rat v l with ph nindi n (*L nd n* 196 )

F ch patient p t per tive circul tion w exam ne l with scillometr and pul e palpati Hi nd ti n wa eexamin l at int rval f 1 6 months In man cases of ren l xclu i n a fre h arteri g ph was p rf rmed In general the sign and yn pt m r m ined c n i t nt

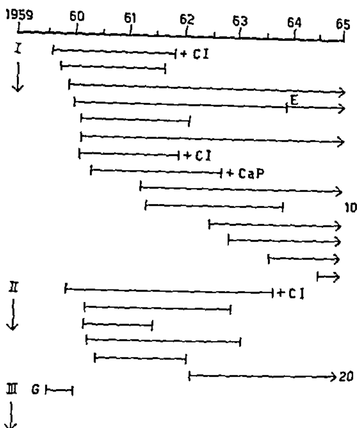



*Figure 2*

## RESULTS

The results obtained with the different methods are shown in the accompanying tables Figures 2 3 and 4 indicate the methods used in Groups I II and III (degrees of progression) together with the primary results and the secondary results—the time the vessels remained open Figure 2 shows the vein by pass (VBP) cases of the thigh Figure 3 the femoral endarterectomies (FE) and teflon prostheses (TP) and Figure 4 the aorta iliac endarterectomies (A–I E) Thus the tables give all four variables in summarized form

It can be seen that most of the VBP cases were followed for almost five years In the first degree cases the circulation of 14 patients was

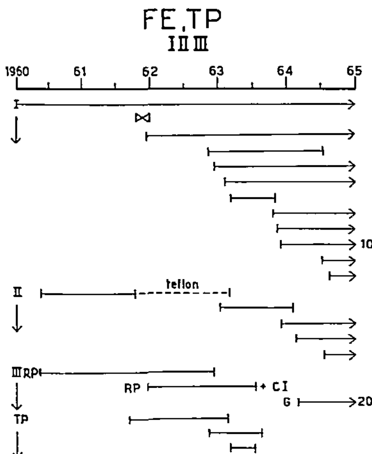



*Figure 3*

good the grafts of 8 remained open 3 died and in 3 there was renewed occlusion Of the 10 cases followed for an average of 4–5 years 3 died and in 3 there was reocclusion of the 7 of these patients who remained alive the circulation of 4 stayed open—giving an overall result of roughly 50-60 per cent Of the second degree cases the vessels of 6 remained open for an average of approximately three years one died and in one there was renewed occlusion The third degree gangrene patient had to be amputated some six months after reconstruction

The femoral endarterectomy cases were followed for a shorter time —average 1 7 years Of the 12 first-degree cases four suffered renewed occlusion—one of them as a primary result—and one underwent another endarterectomy Of the 7 first degree cases followed up for an

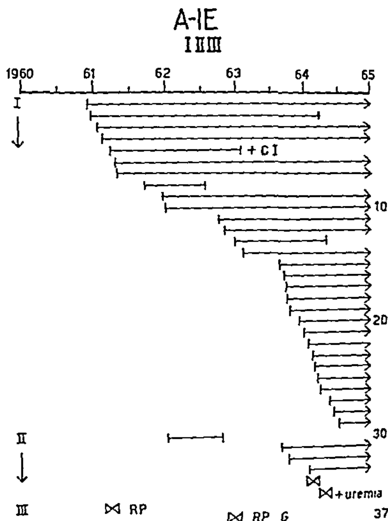



*Figure 4*

average of over two years 4 remained open. Thus the duration of positive results (50–60 per cent) was less than it was in the ABP material. In the 2 occluded cases among the second degree patients the average open time was a little over one year. A better result was obtained in the three third degree cases: the extremity was preserved for an average of over two years and the rest pain and gangrene were cured. Teflon prostheses were used in the third degree cases and the open time averaged nine months. The one case that remained open for over a year was a common iliac common femoral by pass.

Among the aorta iliac and iliac cases, ten of the older ones were

followed up for about 4 years Of these two reoccluded and there was one death so 80 per cent remained open Of all the 29 such cases with first-degree indications three reoccluded and one died Thus the result was relatively good about 90 per cent One of the six second-degree cases died one suffered primary reocclusion, one reoccluded secondarily and three remained open The death was due to uremia The primary reocclusion was due to a long endarterectomy which extended along the whole iliac artery Half of the cases were still open a year after operation In both of the third-degree cases reocclusion was a primary result Owing to their rest pain and gangrene they had to be amputated

On comparing the results VBP in the area of the thigh proved to be somewhat better than endarterectomy though the difference is not statistically significant The follow up time for the endarterectomy cases was shorter It is impossible to state definitely which is the best method For the second-degree cases the VBP method proved to be somewhat better but in the third degree cases endarterectomy produced notably better results and teflon prostheses were ineffective

The best results in the whole material were achieved by endarterectomy in the aorta iliac occlusions During the whole follow-up time 80 90 per cent of the cases observed for an average of 3 5 years remained open The corresponding percentage achieved simultaneously by femoral VBP was 50–60 per cent Operation proved to be beneficial in the second-degree cases but only slightly so in the third-degree cases

A comparison between the operative results of the first second and third-degree cases confirms that the higher the degree of severity the worse are the results The results were still positive in the second-degree cases In Group III the results did not last long though when we performed endarterectomy it did save the extremity in some cases

One of our patients died during the operation owing to bleeding from the vena cava and one died post-operatively from uremia Six died during the follow up time In five of these the cause of death was cardiac infarction and in one lung cancer (Cl CaP)

## DISCUSSION

Indications for surgical treatment of arteriosclerosis in the extremities are still a subject of wide discussion At all events the result is clearly correlated to the degree of progression of the disease and the localization of the occlusion in the extremity Where the changes have

to a large area the circulation can be improved in part of the extremity but the latter does fully regain its normal function even if, in some cases, it can be saved from amputation. Therapy is unable to keep pace with progression and, as the years go by, a large part of the extremity will become diseased again. As the case is followed, new localizations are found and the disease appears in the other extremity. Surgery provides no final cure for arteriosclerosis.

One indication for operation is a limb beset by rest pain and gangrene that seems to call for amputation. It must not be amputated without an arteriography. In some cases, local reconstruction of the blood vessel can improve the circulation to such an extent that the symptoms cease despite the diffusion of the changes, and the limb saved—for a time at least. Rest pain is a case at point. It does not in itself indicate amputation, but obviously something must be done to relieve severe pain.

In cases in which the disease is diffuse or peripherally occlusive (Groups III and II), a functional disproportion remains in the circulation after the operation. There is a scarcity of bloodflow to and from the reconstructed area. This means that the flow (volume velocity) does not decrease in the normal ratio, and the artery is always predisposed to thrombosis. The greater this physiological disproportion, the greater the danger of an unsuccessful operation. Post-operative anti-coagulation may prevent the onset of thrombosis to some extent.

Primary failure of operation is very seldom due to technical errors. In some cases the vessels have become so defective that endarterectomy cannot be performed. In addition, the saphenous vein may be too narrow. An arteriotomic suture of the femoral artery without a patch gives rise to narrowing, which in its turn accelerates renewed occlusion. The iliac vessels are usually wider than normal after an endarterectomy and *do not require patches for arteriotomy*. During an endarterectomy every effort should be made to remove the thickened intima and media as completely as possible, as well as the calcification. In my experience the common iliac artery holds out against the blood pressure provided the outer part of the media (lamina elastica externa) is preserved. In this case, too, the result of the operation is more permanent. Part of the arterial wall can be replaced by teflon patches. In not one case in our material has an artery ruptured after endarterectomy.

An investigation of the reasons for post-operative occlusion, comprising 15 arteriographies, indicated the following: the most important reason was arteriosclerotic progression—*i.e.* new narrowings on the

distal or proximal side of the area operated. Owing to the physiological disproportion this had caused in the circulation the point of reconstruction had become reoccluded. Progressive arteriosclerosis was also responsible for the poorer results and eventual reocclusion among the second and third degree cases. Technical errors were responsible for only a very few reocclusions.

On comparing VBP and endarterectomy as methods of treating femoral occlusions it must be remembered that the material presented here does not permit clear statistical conclusions to be drawn. It is evident however that in the case of local atheroma (first degree arteriosclerosis) endarterectomy is the better method. As the changes due to the disease increase and the occlusion becomes longer the advantages of VBP grow: it produces a better blood vessel than a long endarterectomized artery. The post operative danger of thrombosis is smaller if second-degree cases are treated with VBP. On the other hand endarterectomy is technically easier. Personally I prefer vein by pass to endarterectomy in long femoral occlusions and in cases of narrowing arteriosclerosis in the region of the calf. In treating diffuse third degree arteriosclerosis by means of local reconstruction endarterectomy is the better method.

On the whole many year's experience has shown that the new reconstructive methods of arterial surgery have established their position as a useful productive measure particularly when the indications are right. To give the maximum benefit cases must be brought for treatment at an early stage for in the end the fight against arteriosclerotic progression is doomed to defeat.

## SUMMARY

81 cases of occlussive arteriosclerosis of the lower extremity was operated by reconstructive surgery.

In the thigh vein autograft by pass (VBP) and endarterectomy (FE) were performed. The methods applied in the aorta iliac artery were endarterectomy (A-IE) and in a very few cases teflon prosthesis by pass (TP) (21 + 20 + 37 + 3 = 81).

The degree of arteriosclerotic progression in the extremity was determined by arteriography and from the operative findings. The material was then divided into three groups according to the extent of the disease. First degree cases—the "local" group—were those in which the changes and occlusion were segmental and the proximal and

peripheral artery was almost healthy Second degree cases were those with peripheral changes in addition—the local and peripheral group In the third degree cases the disease had extended over large areas of the extremity these comprised the diffuse changes group (55 (I) + 17 (II) + 9 (III) = 81)

Of the first degree cases in which the thigh was affected 50 60 per cent remained open for 4–5 years after VBP and 2 years after endarterectomy In the aorta and iliac cases the result was 80–90 per cent for a follow up time 3–4 years

Among the second degree cases those treated by VBP remained open for 2–3 years those treated by endarterectomy 1–2 years

In the third degree cases endarterectomy saved the extremity for an average of 1–2 years in optimal cases Rest pain and gangrene were eliminated One patient died during the operation one post operatively (2 5 per cent)


RÉSUMÉ

81 cas d arteriosclerose occlusive de l extrémité inférieure ont ete opérés par chirurgie reconstructive

Dans la cuisse un by pass d autogreffe de veine (VBP) et une endarterectomie (FE) ont ete pratiquees Les methodes appliquees aux aortes iliaques ont ete l endarterectomie (A I E) et dans quelques cas le by pass par prothese teflon (TP) (21 + 20 + 37 + 3 = 81)

Le degre de progression arteriosclerotique de l extremite a été determine par arteriographie et par les trouvailles operatoires Le matériel est divisé en trois groupes selon l extension de la maladie Les cas du premier degre – le groupe «local» – ont ete ceux chez lesquels les modifications et l occlusion etaient segmentaires l artere proximale et peripherique etant pratiquement en bon état Les cas du deuxieme degre sont ceux chez lesquels il y avait en plus des modifications peripheriques – groupe «local et peripherique» Dans les cas du troisième degre la maladie s etait etendue sur une large partie de l extremite ceux ci comprenaient le groupe des «alterations diffuses» (55 (I) + 17 (II) + 9 (III) = 81)

Dans les cas du premier degre chez lesquels la cuisse était atteinte 50 a 60 pour cent restèrent ouverts pendant 4–5 ans apres le VBP et 2 ans apres l endarterectomie Dans les cas aortes iliaques les resultats ont ete 80–90 pour cent pour une periode d observation de 3 a 4 ans

Parmi les cas du deuxieme degre ceux traites par VBP sont restés ouverts pendant 2 3 ans ceux traites par endarterectomie 1–2 ans

Dans les cas du troisième degre l endarterectomie a sauve l extremite pour 1 a 2 ans en moyenne dans les cas optima La douleur du repos et la gangrene ont ete elimines Un malade est decede en cours d operation l autre apres l operation (2 5 pour cent)

## ZUSAMMENFASSUNG

81 Falle von oblitterierender Arteriosklerose der unteren Gliemassen wurden mittels rekonstruktiver Chirurgie operiert

Am Oberschenkel wurden autogene Venenüberbrückungsoperationen (VBP) und Endarteriektomie (FE) ausgeführt Die Methoden welche an der Aorta iliakal Arterie verwendet wurden waren Endarteriektomie (AIE) und in einigen wenigen Fallen Teflonprothese Überbrückung (TP) (21 + 20 + 37 + 3 = 81)

Der Grad der arteriosklerotischen Progression wurde mittels Arteriographie und aus den operativen Befunden bestimmt Das Material wurde dann entsprechend der Ausdehnung der Erkrankung in drei Gruppen eingeteilt Fälle des ersten Grades die lokale Gruppe waren jene bei denen der Verschluss nur auf einen Abschnitt begrenzt und die proximale und distale Arterie beinahe gesund war Falle des zweiten Grades waren jene die zusätzlich periphere Veranderungen aufwiesen-die lokale und periphere Gruppe Bei den Fällen der dritten Gruppe hatte sich die Erkrankung uber weite Gebiete der Gliedmasse ausgebreitet Diese umfassten die diffuse Veränderungsgruppe" (55 (I) + 17 (II) + 9 (III) = 81)

Von den Fallen der ersten Gruppe bei denen der Oberschenkel ergriffen war blieben 50–60 pro zent offen fur 4–5 Jahre nach VBP und zwei Jahre nach Endarteriektomie Bei d n Aorta iliakal Fallen war das Ergebnis 80–90 pro zent fur eine Nachuntersuchungszeit von 3–4 Jahren

Von den Fallen der zweiten Gruppe blieben jene die mittels VBP operiert waren 2–3 Jahre offen jene die mittels Endarteriektomie behandelt waren 1–2 Jahre

In den Fallen des dritten Grades bewahrte die Endarteriektomie die Extremitet in den besten Fallen für einen Durchschnitt von 1–2 Jahren Ruheschmerz und Gangren wurden ausgeschaltet Ein Patient starb unter der Operation ein anderer postoperativ (2 5 pro zent)

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# ARTHRODESIS OF THE ANKLE AS A TREATMENT FOR POST FRACTURE CONDITIONS

By

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Despite the steady development of treatment for fractures the after effects of fractures of the ankle are still a formidable problem This is because fracture of the ankle is a common occurrence and in a considerable proportion of cases the late results of the treatment have been poor *Klossner* (1962) noted poor results in 12 per cent of his material consisting of 403 severe fractures of the ankle Since the ankle joint must carry the whole weight of the body even slight anatomical changes may cause osteoarthritis with pain Arthrodesis is the most reliable treatment for painful conditions of this kind which age merely aggravates

The Orthopaedic Hospital of the Invalid Foundation receives the majority of the cases of unsuccessfully treated ankle injuries in Finland For this reason fusion of the ankle is a comparatively often used procedure in the hospital The purpose of the present study is to ascertain the results of treatment in recent years *Vainio* (1957) published a material on ankle arthrodesis from the same hospital including cases treated during the years 1946–54 This material includes patients treated by ankle fusion from July 1956 to June 1963

## MATERIAL

The material includes 55 patients on whom arthrodesis of the ankle was performed because of post fracture conditions Of these patients 4[illegible] were men and 12 women Age grouping at the first examination was as follows

The youngest was [illegible]0 years of age the oldest 64

Most patients were middle aged manual workers Treatment was sought because of pain which hindered work or rendered it impossible The majority of fractures occurred at work or in traffic accidents so that 42 patients were insured against accident and only 13 were without insurance [illegible]

*Table 1. Age Grouping on First Visit to the Hospital*

| Age | No. |
|---|---|
| 20–29 | 5 |
| 30–39 | 17 |
| 40–49 | 19 |
| 50– | 14 |
| Total | 55 |

The nature of the primary injury is shown in Table 2.

*Table 2*

| | No. | Open fractures | Closed fractures |
|---|---|---|---|
| Trimalleolar fractures | 13 | 7 | 6 |
| Bimalleolar fractures | 24 | 6 | 18 |
| Talar fractures | 9 | | 9 |
| Leg fractures | 9 | 5 | 4 |
| Total | 55 | 18 | 37 |

One third of all fractures and more than one half of the leg fractures were open. In the latter, inflammation, damage to soft parts and long immobilization caused injury to the ankle joint.

In Table 3 the primary treatment is divided into conservative and operative treatment. Fractures receiving operative treatment were closed except for one leg fracture.

*Table 3*

| | Conservative treatment | Operative treatment |
|---|---|---|
| Trimalleolar fractures | 12 | 1 |
| Bimalleolar fractures | 18 | 6 |
| Talar fractures | 7 | 2 |
| Leg fractures | 4 | 5 |
| Total | 41 | 14 |

In this material, pantalar arthrodesis was performed on 7 patients, talocrural arthrodesis after previous subtalar arthrodesis on 2 and talocrural arthrodesis alone on 46.




*Figure 1 a) Radiograph of an ankle showing osteoarthritis after fracture b) The same ankle as in a) four months after arthrodesis by the method of Adams*

Arthrodesis was performed by several methods In anterior arthrodesis the cartilage surfaces of the talocrural joint were removed and a sliding graft taken from the anterior surface of the tibia was embedded in the talus The Adams method comprised fixation of the talus and the tibia with the detached distal end of the fibula which was fixed by screws (Figure 1 a and b) By the compression method the bones with the joint cartilage removed were pressed together by means of a Charnley compression device Screw fixation was used in pantalar arthrodesis with a long screw driven through the calcaneus and talus to the tibia where it must penetrate the cortical bone

Skin necroses were cured during immobilization in plaster and did not prolong the time of recovery Of three infections two subsided after prolonging recovery time by 3 4 months but the third led to amputation In the latter case the compression method had produced bony union but osteomyelitis damaged the leg to such an extent that amputation was considered the best solution This was originally an open fracture case Re arthrodesis was performed in two cases one of w consolidated the other not Fibrous union after talocrural art

does not always cause great inconvenience, which accounts for the small number of re-arthrodeses, since patients were unwilling to undergo further operation.

*Table 4*

| Method | Talocrural arthrodesis | Pantalar arthrodesis | Skin necrosis | Infection | Consolidated | Fibrous union |
|---|---|---|---|---|---|---|
| Anterior Sliding Graft | 14 | | 3 | | 14 | |
| Adams | 22 | | 3 | 1 | 22 | |
| Compression | 6 | | 1 | 1 | 5 | 1 |
| Screw fixation | 2 | 3 | 2 | | 3 | 2 |
| Without fixation | 4 | 4 | 1 | 1 | 5 | 3 |
| Total | 48 | 7 | 10 | 3 | 49 | 6 |

*Table 5*

| | Subjectively | | | Objectively | | |
|---|---|---|---|---|---|---|
| | Good | Satisfactory | Poor | Good | Satisfactory | Poor |
| Fibrious union | | 2 | 4 | | 1 | 5 |
| Consolidated | 27 | 21 | 1 | 43 | 4 | 2 |
| Total | 27 | 23 | 5 | 43 | 5 | 7 |

Subjectively "good" signifies cases where no pain or swelling occurred under strain, "satisfactory" cases where occasional pain occurred under strain but the patient himself felt better than before the operation and "poor" cases where pain from pseudoarthrosis occurred. The only ossified ankle in the "poor" category was in the case which ended in amputation. Of the cases showing fibrous union one was objectively satisfactory; here the X-ray revealed a nonossified layer but mobility could not be clinically observed and the position of the foot was good. Cases showing bony union were considered satisfactory or poor if there was excessive equinus, valgus or, the most harmful of all deviations from a neutral position, varus deformity.

After operation 43 patients returned to the same or corresponding work and 10 to lighter work. Two did not return to work. One of these

was the amputation case the other was a patient on whom subtalar arthrodesis was performed because of pain proceeding from the arthrotic subtalar joint The treatment of both these patients was still unfinished at the time of re examination

## DISCUSSION

On the basis of this material arthrodesis of the ankle appears to be a suitable form of treatment when a harmful deformity or pain remains after the fracture A stiff ankle joint is not noticeably harmful even in heavy work but a painful ankle often prevents work altogether when walking is necessary

After talocrural arthrodesis a considerable increase in the mobility of the subtalar joint can be observed almost regularly This may be so considerable that in clinical examination it makes the estimation of consolidation difficult On the one hand this lessens the harmful effect of fusion but on the other it transfers the strain to the subtalar joint where it may be followed by later osteoarthritis This occurred in a few cases in our series and it was necessary to perform a subtalar arthrodesis later

Slight equinus seems to be advantageous especially in women In one male patient excessive equinus caused so much harm that it had to be corrected Deviations from the neutral position to the varus or valgus position are harmful although the varus position is much more harmful

In this material the best results of talocrural arthrodesis were achieved by the Adams and the sliding graft methods The material is so small however that no definite conclusions regarding the different methods can be drawn *Adams* (1948) using the method which carries his name achieved consolidation in 28 patients out of 30 This method is recommended also by *Watson Jones* (1955) and *Brittain* (1952) *Jansen* (1962) reported consolidation by the Charnley compression method in 24 patients out of 25

Results obtained in the present study are in full accordance with results published elsewhere

Despite appropriate treatment for ankle fractures the frequency of osteoarthritis may be over 30 per cent Since the majority of these cases are painful it is evident that in the future arthrodesis of the ankle will continuously be of importance in the treatment of post fracture conditions

SUMMARY

Fifty five patients on whom talocrural (48) or pantalar arthrodesis had been performed as a treatment for post fracture conditions were re examined Various methods of arthrodesis were used Good results were achieved in 43 cases satisfactory in 5 and poor in 7 These are in accordance with the results published elsewhere Adams method is recommended (Figure 1 a and b)

RESUME

Cinquante cinq malades chez qui une arthrodese talo crurale (48) ou pantalaire a ete pratiquée comme traitement de suites de fractures ont ete reexamines Différentes méthodes d arthrodese ont été utilisées De bons resultats ont ete obtenus dans 43 cas satisfaisants dans 5 et mauvais dans 7 Ceux ci sont publiés ailleurs conformément au résultat La methode d Adams est recommandee (Figure 1 a et b)

ZUSAMMENFASSUNG

Funfundfunfzig Patienten an denen eine talocrurale (48) oder pantalare Arthrodese als Behandlung von Zustanden nach Bruchen ausgefuhrt worden war wurden nachuntersucht Verschiedene Methoden der Arthrodese wurden verwendet Gute Ergebnisse wurden in 43 Fallen zufriedenstellende in 5 und schlechte in 7 Fallen erhalten Dies ist in Übereinstimmung mit den von andrerer Seite veröffentlichten Ergebnissen Adams Methode wird empfohlen (Figure 1 a und b)


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From the Orthopaedic Clinic Borås Sweden (Chief Folke Ståhl M D )

# SITTING—AN ELECTROMYOGRAPHIC AND MECHANICAL STUDY

*By*

BERTIL KNUTSSON KUNO LINDH & HANS TELHAG

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Technical advances in the last few decades have resulted in an increasing number of sedentary occupations as well as an increase in the average number of hours a day people spend in the sitting posture This has in turn led to changes in the functional use of skeletal and muscular systems People walk less and less and sit more and more in cars or other vehicles During leisure hours they sit before the television screen etc An ever increasing number of people complain of back pain when sitting It was thought that examination of subject with and without back symptoms might prove useful in he design of a chair providing the maximum degree of rest for the back

The mechanics and statics of sitting have been carefully studied by *Schobert* (1962) He showed roentgenographically that on a change of posture from standing to sitting the pelvis is rotated on the average 40 and that this rotation is accompanied by a simultaneous compensatory kyphotic movement of the lumbar spine During upright sitting the backward rotation is reduced and the kyphosis diminished by contraction of the muscles of the back (Figure 1)

Before the publication of Schobert s work opinions had differed widely on the statics of sitting (*Staffel* 1884 *Schulthess* 190) *Spitsy* 1926 *Fick* 1911 *Heuer* 1930 and others) All investigators interested in the problem of sitting had however agreed that a support for the back was a most important part of a proper chair *Staffel* (1884 and 1889) wrote that chairs are designed more for the eye than for the back Like *Meyer* (1873) he meant that it is impossible to rest properly in a chair without a back Meyer recommended a support at the level of Th XII *Staffel* concluded that the position of the back in the sitting po should be as near as possible to that during standing i e

## SUMMARY

Fifty-five patients on whom talocrural (48) or pantalar arthrodesis had been performed as a treatment for post-fracture conditions were re-examined. Various methods of arthrodesis were used. Good results were achieved in 43 cases, satisfactory in 5 and poor in 7. These are in accordance with the results published elsewhere. Adams' method is recommended (Figure 1 a and b).

## RÉSUMÉ

Cinquante-cinq malades chez qui une arthrodèse talo-crurale (48) ou pantalaire a été pratiquée comme traitement de suites de fractures ont été reexaminés. Différentes méthodes d'arthrodèse ont été utilisées. De bons résultats ont été obtenus dans 43 cas, satisfaisants dans 5 et mauvais dans 7. Ceux-ci sont publiés ailleurs conformément au résultat. La méthode d'Adams est recommandée (Figure 1 a et b).

## ZUSAMMENFASSUNG

Fünfundfünfzig Patienten, an denen eine talocrurale (48) oder pantalare Arthrodese als Behandlung von Zuständen nach Brüchen ausgeführt worden war, wurden nachuntersucht. Verschiedene Methoden der Arthrodese wurden verwendet. Gute Ergebnisse wurden in 43 Fällen, zufriedenstellende in 5 und schlechte in 7 Fällen erhalten. Dies ist in Übereinstimmung mit den von andrerer Seite veröffentlichten Ergebnissen. Adams' Methode wird empfohlen (Figure 1 a und b).


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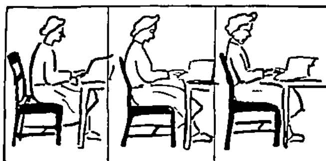


*Figure 3 Akerblom's chair*

ate contraction of the muscles of the back If the muscles become tired the body falls forward and kyphosis occurs He therefore recommended a chair with an upper backward slope for the thoracic spine (Figure 2)

*Schede* 1935 on the other hand recommended a backward slope of the entire back of the chair and *Schulthess* (1905) believed 100 –105 to be a suitable angle between the seat of the chair and the back of school benches *Morant* (1947) recommended a corresponding angle of 110 for the alert position and 110–125 for the resting position *Sallfors* (1941) was of the opinion that the support for the back should be concentrated below the shoulder blades and above the diaphragm while *Kindstrand* (1944) recommended a support for the lumbar region *Vernon* (1924) stressed the importance of changing the position often in order that the muscles under tension may rest At the same time he pointed out that the designers of chairs believe that there is only one ideal position In 1949 *Akerblom* said that the most important criterion for a good chair is that it should allow the assumption of different resting positions He spoke of three different resting positions

1 With the trunk bent forward without support for the spinal column
2 Sitting with a lumbar support
3 Sitting with a backwardly inclined support providing good support for both the lumbar and the thoracic spine

*Akerblom* who used electromyography showed that support of the lumbar spine is sufficient to rest the back muscles which he thought was the most important thing The height of the seat of the chair i e the distance between the floor and the seat has also been discussed The height recommended has varied between 38 cm and 47 cm



*Figure 4 The examination chair*

In order to form an opinion of different sitting postures and of individual variations we used a specially designed chair made at the workshops of the department. The chair was designed so as to allow adjustment of the height of the seat by shortening or lengthening its legs (Figure 4).

The back has a transverse support down near the seat and a wider one higher up. The back is fixed to the posterior edge of the seat with a hinge allowing forward and backward adjustment of the angle of the back. A protractor is fitted to the chair so that it is possible to read the angle between its seat and its back. Between the upper and lower transverse parts of the back of the chair is a pad which can be adjusted in the vertical and horizontal planes. For adjustment in the horizontal plane there is a special screw device with an inbuilt scale. This makes it possible to read the exact position of the pad, i.e. it provides a measure of lordosis or kyphosis in centimetres.

The patient was first allowed to sit comfortably in the chair with the sacrum and thoracic spine resting against the lower or upper transverse part of the back of the chair. The height of the seat was adjusted and set at such a level that the knee was flexed 90°. The arms were

relaxed with the hands on the thighs The head was kept directed forwards and the patient was asked to fix his eyes on a point at the level of the face The muscular activity was recorded electromyographically by introducing an electrode into the m sacrospinalis on each side at the level of Th XII–LI The electrodes were connected to electromyographic channels 1 and 3 At the same time channel 2 served as a calibration channel The examination was carried out first with an angle of 100 between the seat and back of the chair and then with an angle of 110 At each angle recordings were made without the dorsal pad called 0 position and then with the pad at the level of L IV screwed forward 1 2 and 3 cm and resulting in corresponding degrees of lordosis called +1 +2 and +3 positions Measurements were then made again in the 0 position after which the pad was screwed backward 1 2 and 3 cm with corresponding kyphosis called —1 —2 and —3 positions

The material consisted of four groups

1 Healthy subjects
2 Patients with back pain without roentgenographically demonstrable changes back weakness
3 Back pain with slight roentgenographic changes disk degeneration
4 Back pain with severe roentgen changes spondylosis deformans

*Group 1* This group consisted of 40 healthy subjects (20 males and 20 females) who had never had back symptoms The males were doing their military service in an infantry regiment and the females were nurses physical therapeutists and other hospital personnel The average age of the males was 19 3 years (range 19–20 years) and the average height 180 1 cm (range 170–188 cm) The mean age of the females was 23 1 (range 16–55 years) and the average height 164 2 cm (range 158–175 cm)

*Group 2* This group with back pain without roentgenographic changes consisted of 10 subjects (3 males and 7 females) None of them showed any roentgenologic or neurologic changes and in all of them the mobility of the back appeared normal The average age of the males was 33 3 years (range 16–51 years) and the average height 171 6 cm (range 168–180 cm) The mean age of the females was 32 4 y (range 17–50 years) and the average height 163 6 cm (range 157 cm)

*Figure 5 Number of examinations in different positions*

| 100 | −3 | −2 | −1 | 0 | +1 | +2 | +3 |
|---|---|---|---|---|---|---|---|
| Group 1 normal cases | 3 | 16 | 28 | 40 | 38 | 36 | 30 |
| Group 2 insuff dorsi | 0 | 4 | 9 | 10 | 10 | 10 | 5 |
| Group 3 degeneratio disci | 0 | 2 | 8 | 10 | 10 | 10 | 8 |
| Group 4 spondylosis deform | 0 | 5 | 9 | 10 | 10 | 10 | 5 |

| 110 | −3 | −2 | −1 | 0 | +1 | +2 | +3 |
|---|---|---|---|---|---|---|---|
| Group 1 normal cases | 4 | 13 | 23 | 40 | 30 | 30 | 25 |
| Group 2 insuff dorsi | 0 | 2 | 7 | 10 | 10 | 10 | 5 |
| Group 3 degeneratio disci | 0 | 2 | 7 | 10 | 10 | 10 | 9 |
| Group 4 spondylosis deform | 0 | 2 | 9 | 10 | 10 | 10 | 4 |

*Group 3* This group with back pain with slight roentgenographic changes (disk degeneration) consisted of 10 persons (8 males and 2 females) None of them showed neurologic signs and in all the mobility of the spine was practically normal The average age for the males was 42 6 years (range 26–58 years), average height 178 4 cm (range 171–191 cm) The average age of the females was 52 0 years (range 51–53 years) and the average height 164 5 cm (range 164–165 cm)

*Group 4* This group with back pain and severe roentgenographic changes consisted of 10 persons (7 males and 3 females) All had roentgenologically demonstrable changes of spondylosis deformans without neurologic signs and in all of them the mobility of the spine was decreased The average age of the males was 59 4 years( range 43–68 years) average height 173 1 cm (range 164–182 cm) The average age of the females was 49 years (range 42–59 years) the average height 163 3 cm (range 159–167 cm)

Groups 2 3 and 4 consisted of patients who had sought advice at the outpatient department of orthopedic surgery because of back pain

All of them were examined electromyographically in the O position *i e* without the pad as well as when the angle between the seat and the back of the chair was 100 and when it was 110 On the other hand examination was not always possible with the use of the pad especially in position —3 owing to decreased mobility of the spinal column The patients who were examined electromyographically in the various positions with an angle of 100 and 110 between the seat and the back of the chair are summarized in Figure 5

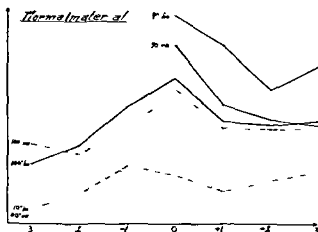



*Figure 6 Group 1 Normal cases*

## RESULTS

Of the curves obtained for the individual subjects a mean curve was drawn for each group for an angle of 100 and 110 between the seat and the back of the chair and for the right side and for the left respectively

In Group 1 normal material (Figure 6) the curves for the right side and those for the left which often differed from one another in one and the same individual fused in the mean curve

Furthermore a small group examined with an angle of 90 between

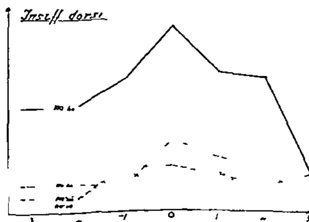



*Figure Group Back weakness*

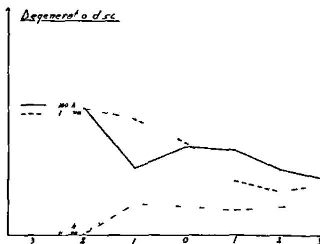


*Figure 8. Group 3. Disc degeneration*

the seat and the back of the chair showed a clearly higher activity than for the other two angles. The activity noted at an angle of 100° was higher than that recorded at an angle of 110° and the highest activity was regularly noted for the O position.

In Group 2, patients with back pain without roentgenographic changes or back weakness (Figure 7), there was an increased activity on the right side at angle of 100 as well as of 110° between the seat and the back of the chair.

This is remarkable because most of the subjects in this group had a feeling of fatigue on the right side where muscular tension was found clinically to be higher. Six of the subjects in the group showed this picture while only one had left sided symptoms. As to the effect of the slope of the back of the chair, the activity was lower at 110° than at 100°.

In Group 3, with slight roentgenographic changes and disk degeneration (Figure 8), the symptoms were equally common on both sides. As in the normals, the activity on both sides was higher at 100° than at 110°.

In Group 4, with severe roentgen changes and spondylosis deformans (Figure 9), the symptoms were equally frequent on both sides. In this group it is remarkable that both the right and the left curves for the examinations with the use of the pad (kyphosis) showed a much higher activity at 110° than at 100°. This was thus the opposite to that found in the other three groups.

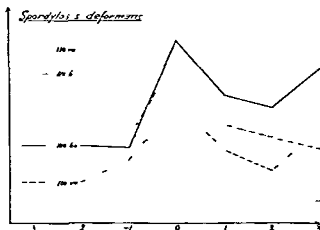
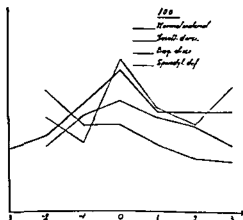



*Figure 9 Group 4 Spondylosis deformans*

It should be added that these patients preferred to sit at 100 than at 110 while in the other three groups the subjects preferred to sit with the back at 110 Furhermore in all positions the activity was much higher in this group with severe roentgen changes than in the other groups studied There is possibly a correlation between the roentgen changes and fixation and then probably because of muscle contractures

Finally the right and left values in each group were pooled and their means were calculated At 100 between the seat and back of the chair (Figure 10) it was found that in the 0 position the activity was



*Figur 10 100 betw n the s at and th back of the cha r*

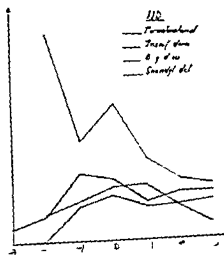


Figure 11. 110 ... between the seat and the back of the chair

It would thus appear that at least 2 designs are desirable one with an angle of 110 between the seat and the back of the chair for persons with a normal spine and one with an angle of 100 for persons with decreased mobility of the spinal column In both cases the back should be curved to fit a spinal column with 1–2 cm lordosis

*Figure 19 Most restful and comfortable position*

| Position of the saddle cushion | | 0 | 0 and +1 | +1 | +1 and +2 | +2 | +2 and +3 | Don't know |
|---|---|---|---|---|---|---|---|---|
| 100 | Group 1 | 5 | – | 29 | | 4 | 1 | 1 |
| | Group 2 | 1 | – | 7 | | 2 | | |
| | Group 3 | 1 | 1 | 6 | – | 2 | | |
| | Group 4 | 1 | – | 8 | – | 1 | | |
| | Sum | 8 | 1 | 50 | – | 9 | 1 | 1 |
| 110 | Group 1 | 3 | – | 25 | – | 2 | 1 | 9 |
| | Group 2 | 1 | – | 7 | – | 2 | | |
| | Group 3 | | | 7 | 1 | 2 | | |
| | Group 4 | | – | [illegible] | – | | 1 | |
| | Sum | 4 | – | 46 | 1 | 8 | 2 | 9 |
| | Total sum | 12 | 1 | 96 | 1 | 17 | [illegible] | 10 |

## SUMMARY

In order to study different sitting positions and individual differences between such positions a special chair was designed with an adjustable seat height adjustable angle of the back and a back pad adjustable in the vertical as well as the horizontal plane With an angle of 100 and of 110 between the seat and the back of the chair the electromyographic activity was recorded in the long extensors of the back without and with the back pad screwed forwards 1 2 and 3 cm with consequent lordosis and backwards 1 2 and 3 cm with a corresponding degree of kyphosis The material studied consisted of

1 Subjects with healthy backs
2 Patients with back pain without roentgenographically demonstrable changes back weakness
3 Patients with back pain with slight roentgenographic changes disk degeneration and

4 Patients with back pain with severe roentgenographic changes spondylosis deformans

None of the subjects had neurological signs

It seems that two different designs of chairs are desirable one with an angle of 110 between the seat and the back of the chair for persons with a normally mobile spine and one with an angle of 100 for persons with decreased mobility of the spinal column In both cases the back should be curved to fit a spinal with 1–2 cm lordosis

## RESUME

Afin d etudier differentes positions assises et les differences individuel les entre ces positions une chaise speciale a été construite avec hauteur adaptable du siege angle adaptable du dossier et un coussin du dossier adaptable aussi bien dans le plan vertical qu horizontal Avec un angle de 100 et de 110 entre le siege et le dossier de la chaise l activité electromyographique a ete enregistree pour les longs extenseurs du dos sans et avec le coussin du dos avance de 1 2 et 3 cm donc en lordose constante et coussin recule de 1 2 et 3 cm avec un degre correspon dant de cyphose Le matériel d observation etudié se composait de

1 Sujets avant le dos normalement sain
2 Malades avant des douleurs dorsales mais sans altérations radiologiquement decelables faiblesse dorsale
3 Malades ayant des douleurs dorsales et presentant de legères modifications radiologiques degeneration discale et
4 Malades avant des douleurs dorsales avec de graves modifications radiologiques spondylose deformante

Il semble que deux modeles differents de chaises sont souhaitables l un avec un angle de 110 entre le siege et le dossier de la chaise pour les personnes avant une colonne vertébrale normalement mobile et l autre avec un angle de 100 pour les personnes avant une mobilite diminuee de la colonne vertébrale Dans les deux cas le dos doit etre courbe de maniere a placer la colonne vertebrale avec 1–2 cm de lordose

## ZUSAMMENFASSUNG

Um die verschiedenen Stellungen im Sitzen und die individuellen Ver schiedenheiten zwischen derartigen Stellungen zu studieren wurde ein

besonderer Stuhl mit verstellbarer Sitzhohe verstellbarem Rücken winkel und einem Rückenkissen das sowohl in der vertikalen als auch in der horizontalen Ebene verstellbar war konstruiert Bei einem Win kel von 100 und von 110 zwischen dem Sitz und dem Stuhlrücken wurde die elektromyographische Aktivitet der langen Rückenstrecher ohne und mit Rückenkissen das 1 2 und 3 cm mit folgender Lordose nach vorwarts und 1 2 und 3 cm nach rückwarts mit folgender Kyphose geschraubt wurde verzeichnet

Das untersuchte Material bestand aus
1 Personen mit gesunden Rücken
2 Patienten mit Ruckenschmerzen ohne röntgenologisch nachweis baren Veränderungen Rückenschwache
3 Patienten mit Rückenschmerzen und leichten rontgenologischen Veränderungen Scheibendegeneration und
4 Patienten mit Rückenschmerzen und schweren rontgenologischen Veränderungen Spondylosis deformans

Es ergibt sich daraus dass zweierlei Konstruktionen wünschenswert sind die eine mit einem Winkel von 110 zwischen Sitz und Stuhlruc ken fur Personen mit normal beweglicher Wirbelsäule und eine andere mit einem Winkel von 100 für Personen mit verminderter Beweglich keit der Wirbelsäule In beiden Fallen sollte die Ruckenlehne so ge krummt sein dass sie einer Wirbelsäule mit 1–2 cm Lordose ent spricht

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